In Context

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#24

Dear Friends,

Often it's hard to recognize that you've entered a period of major transition until you are well into it. That's the way it's been for us. In putting together this issue of *In Context* it fully dawned on us how much change has been going on. Here's some of what we mean:

Craig has just completed his four-year doctoral program in sustainability education at Prescott College in Arizona. (See the story in "News from the Institute.") It's been a long process for him—paid for by a full-tuition scholarship—but the work never carried him far from his Nature Institute activities. Some of his dissertation focused on his beloved whole-organism studies, while other parts gave him an opportunity to assess the Institute's educational activities at a deeper level than ever before. Out of this research will come, we believe, a re-thinking and re-enlivening of our growing educational work.

Meanwhile, as you will read in "An Unexpected, Submicroscopic Journey," Steve has found himself transported into an entirely unforeseen line of research that not only reaches into the heart of modern science, but also promises remarkable new opportunities for bringing phenomenological perspectives into dialogue with geneticists, genetic engineers, synthetic biologists, and biologists in general. The fruits of this work, as you will see, are already beginning to appear.

Then there's Henrike, who has long carried the Institute's offerings in projective geometry, and light and color. Quite apart from the fact that over the past couple of years she has taken on work in astronomy, she is now being drawn more deeply into a study of how concepts are formed in science and how abstractions can be untrue to human experience and phenomenological observation.

Another transition—less happy in some regards, but also colored by the good feeling resulting from years of cheerful and reliable work by Gloria Kemp, our trusted office manager—involves Gloria's long-planned retirement in October. We are heartened that Gloria will not be leaving a void, since two new staff members are joining us. Linda Bolluyt will take on office management duties and Sarah Hearn will help with outreach and program development. Welcome, Linda and Sarah!

And then, of course, there is the transition involving the home for the Institute. You will find a brief report about our planned expansion in the News section. Surely, it is hard these days—with one economic or ecological catastrophe after the next plaguing society and the planet—to see a way forward and to dare to take bold steps. But all the exploitation, mismanagement, egotism, short-sightedness, and political posturing are shouting at us to change our ways. This is not a time for hesitation in counteracting these prevailing tendencies. The Nature Institute is not hesitating.

Craig Holdrege | Steve Talbott

The Nature Institute

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A Shared Existence

Milkweed and Its Myriad Companions

Craig Holdrege

In this issue we conclude Craig's three-part sketch of the milkweed plant. The first part (Fall, 2009) introduced the milkweed and described its life cycle. Part 2 (Spring, 2010) dealt with the elaborate drama of milkweed pollination. In this issue Craig looks at the intimate interaction between milkweed and the many organisms that share in its life.

We have already seen that common milkweed is an important part of the life of insects that feed on its nectar. Observing nectar feeders on common milkweed, Southwick identified representatives from 15 different orders of insects (and one hummingbird species). Nectar was taken mainly during the day, but also during the night by a variety of nocturnal moths. But these nectar-feeding insects represent only a minority of the insects and other arthropods that interact with milkweed. In the late 1970s Dailey and his colleagues carried out surveys of bugs (Hemiptera) and beetles (Coleoptera) on common milkweed. Over the course of ninety days they found 132 different species of beetles, 18 of which they considered common visitors, since they collected more than 50 specimens of each of these species. They collected 45 species of bugs, 5 of which were common visitors according to the same criterion. Milkweed teems with insect life.

For many insects, milkweed is certainly a small and transient part of their habitat—or speaking functionally, a minor part of their ecological niche. They may nibble on the leaves and flower buds, or drink some nectar and then move on to other plants. As predators they may, like the bug *Phymata fasciata*, hide in the thicket of milkweed stems, leaves, and flowers, waiting for their prey of flies and small wild bees. And then there are the milkweed specialists, which I will discuss below, that feed almost exclusively on milkweeds. So milkweed provides food and a microhabitat for a multitude of organisms. Its exuberant growth—in rhizomes, stems, leaves, flowers, fruits, and seeds—allows abundant insect life to orient around it.

Milkweed's Specialized Insect Companions

There are at least 10 species of insects that feed only on common milkweed or other closely related milkweeds in the genus *Asclepias* (see table and photographs). None of these specialist species is a nectar feeder; rather, they feed on milkweed rhizomes, shoots, leaves, flowers, or seeds. The most well-known of these is the monarch butterfly


Caterpillar (left) and adult (right) of monarch butterfly (Danaus plexippus)

Milkweed-Specific Herbivores

Species	Primary Larval Food	Conspicuous (larva & adult)	Sequesters cardiac glycosides?
Monarch Butterfly (*Danaus plexippus*)	Foliage of common milkweed and other milkweed species	Yes	Yes
Milkweed Tussock Moth (*Euchaetes egle*)	Foliage of milkweeds and dogbanes (Apocynum)	Larva, yes: Cryptic adult	Larva: yes; Adult: little
Dogbane Tiger Moth (*Cycnia tenera*)	Foliage of milkweeds and dogbanes	No (larvae beige; adult white)	Yes
Red Milkweed Beetle (*Tetraopes tetraopthalmus*)	Larvae: rhizomes of common milkweed; adult: leaves and flowers of common milkweed	Yes	Yes
Milkweed Leaf Beetle (*Labidomera clivicollis*)	Foliage of common and swamp milkweeds	Yes	Yes
Seed Weevil (*Rhyssomatus lineaticollis*)	Pith common milkweed stems	No	No
Large Milkweed Bug (*Oncopeltus fasciatus*)	Seeds of common and other milkweeds	Yes	Yes
Small Milkweed Bug (*Lygaeus kalmii*)	Sap of common milkweed	Yes	Yes
Milkweed Aphid (*Aphis asclepiadis*)	Sap feeder on a few milkweed species	No (cryptic)	Unknown
Leaf Mining Fly (*Liriomyza asclepiadis*)	Inside of milkweed leaf tissue	No (cryptic)	Unknown

(*Danaus plexippus*). The adult butterfly lays its eggs on the leaves of common milkweed, the larvae live from its leaves and the milky sap the plants contain, and the adults drink from the flower nectar, although they are not restricted to milkweeds.

What is fascinating about the monarch and some of the other milkweed specialists is that they do not just feed on the plants, digest the substances, and then build up their own body substances. Rather, they store some of the components of the milkweed sap in their body. When a milkweed stem or leaf is damaged, it exudes a white sap. All you have to do is to scratch the stem with your finger nail and the white sap oozes out and streams down the stem until it gradually hardens. When, for example, a monarch larva bites into a leaf vein or stalk, the sticky (latex-containing) milky sap seeps out and the larva ingests it. It draws out of the sap a particular group of substances known as cardiac glycosides (cardenolides), and instead of breaking them down or excreting them, it stores them in its tissues. The concentration of cardiac glycosides in the tissues of a monarch is substantially higher than it is in the tissues of common milkweed. Interestingly, it is not only the larva that sequesters these substances; they are also retained in the adult, who has gone through the radical metamorphosis from caterpillar to butterfly. So part of the milkweed remains as an essential part of its insect predators.

Cardiac glycosides are bitter tasting and can disrupt the ionic balance of a number of different cell types in animals, including heart muscle, vascular smooth muscle, neurons, and kidney tubules. In high doses they can be fatal to an animal, but in nature this will rarely happen, since they cause vomiting in pre-lethal doses. We would imagine that common milkweed is protected against herbivores by the cardiac glycosides in its sap.

Clearly, however, the sap does not prevent specialist herbivores from feeding on milkweed and sequestering cardiac glycosides, although some of these specialists avoid taking in large amounts of sap while feeding. The monarch and red milkweed beetle are known to bite into a milkweed leaf vein near the base of the leaf, which then exudes sap that flows back out of the more distally-located veins. The insect then crawls to the periphery of the leaf and begins to feed from the part of the leaf that now contains little sap.

Unsurprisingly, researchers believed that by sequestering cardiac glycosides, milkweed predators may be protected against their own predators. Beginning in the 1960s, researchers began testing this hypothesis and, as Malcolm concludes in a review, "much evidence is published to show that many prey species are well defended against predators by the presence of cardenolides."

So milkweed is helping those insects that prey on it become better protected from their own predators. This is, in a sense, a paradoxical situation in which a plant is providing protection for its predators, which increases the likelihood that there will be more predators to feed on it. Theoretically, one could think that these specialists might eradicate milkweed. But no observations indicate that milkweed populations are significantly harmed by the specialist herbivores associated with them. And it is not as if the monarch or other milkweed specialists have no predators—both monarch adults and larvae are preyed upon at least occasionally by some birds, mice, ants, dragonflies, and wasps, and the larvae can be parasitized by flies and wasps.

Most of the milkweed specialists that sequester cardiac glycosides are brightly colored. (Within a Darwinian framework one interprets such coloring as warning coloration, also called aposematic coloration. The theory is that the bright colors and patterns evolved as a warning sign "keep off.") Hartman noticed an additional correlation, namely that the brightly-colored, cardiac glycoside-storing herbivores tend to move around the plant a good deal when feeding, eating only small amounts and rarely doing significant damage even to a single shoot. The conspicuous caterpillars of the milkweed tussock moth, in contrast, aggregate on a shoot and can denude it of leaves, leaving only the skeleton of the larger veins. Interestingly, tussock moth caterpillars, which sequester cardiac glycosides, metamorphose into inconspicuous (cryptic) nocturnal moths, that do not sequester appreciable amounts of cardiac glycosides.

As an adult, the monarch butterfly migrates south. The monarchs east of the Mississippi fly as far as 4,800 km to Mexico, where they overwinter. "Amazingly, these butterflies fly from their summer breeding range, which spans more than 100 million hectares, to winter roosts that cover less than 20 hectares, often to the exact same trees, year after year" (Solensky). The expansive extent of the summer range corresponds to the range of common milkweed and a number of other milkweed species. Along the way of their migration, they feed on milkweed nectar and the nectar of other flowers. Their range contracts to the small overwintering area in Mexico, where they are temporally and spatially separated from milkweed. However, they still carry small traces of the plant in their bodies through the cardiac glycosides. The next spring they migrate back north and many of these adults mate, lay eggs, and die in the southeastern U.S. Their offspring feed on southern milkweeds, metamorphose, and the adults fly north to find common milkweed flowering in the northern summer. The life cycle begins anew.

A Milkweed Beetle's Life

While the life history of an individual monarch can span nearly a whole continent, the life history of a red milkweed beetle (*Tetraopes tetraophthalmus*) is much more tightly linked to a local common milkweed population. I will describe this relation in some detail. About the time a colony of milkweeds begins to flower, bright red milkweed beetles crawl out of the ground and spread out onto milkweed shoots—an insect version of flowering. They crawl around on the plants and may fly short distances. They generally don't leave the area of the colony. They begin feeding—on leaves, but mainly on flowers. When a milkweed colony is at a high point in flowering, the red milkweed beetle has its peak in population density. The adults

Red milkweed beetle
(Tetraopes tetraophthalmus)

Milkweed leaf beetle
(Labidomera clivicollis)

Nymph (left) and adult (right) of the large milkweed bug
(Oncopeltus fasiatus)

Milkweed tussock moth larvae
(Euchaetes egle)

live for about three to four weeks, which corresponds to the main phase of flowering. The synchrony between adult beetle and flowering milkweed is striking. In a colony that flowers later in the year, the beetles emerge later. It could be that the temperature of the soil helps to coordinate this synchrony, since both shoot development in milkweeds and pupation in the milkweed beetle are temperature-dependent.

The beetles mate and the female moves to a nearby grass plant or other hollow-stemmed old-field plant and nibbles a hole in the stem, crawls inside and lays her eggs. This is the one phase of the life cycle that is not dependent on milkweeds. When the eggs hatch, the larvae crawl down into the ground and move to the milkweed rhizomes. There they begin to feed, both on the inside and outside of the rhizomes. They feed exclusively on milkweed rhizomes. They can do considerable damage to short sections of a rhizome, but never have a significant detrimental effect on a colony as a whole. While the colorless larvae are busily feeding below ground on the rhizomes, the fiery red adults have died. The larvae feed until early fall, when they move out of the rhizomes and overwinter in the soil, near the rhizomes, as large pre-pupae. They do not feed during this time. Both milkweed and pre-pupae are quiescent during the winter. Only when the soil reaches a temperature of about 17 to 18 degrees Celsius does the pre-pupa become active—not through movement or feeding, but through metamorphosis. It forms a pupa out of which the adult beetle soon emerges. It breaks through the cocoon and digs its way out of the soil to emerge in a forest of milkweeds, where it begins to feed. The next adult generation begins its short life.

When we reflect on such relationships between two kinds of organisms, a plant and an animal, the boundaries between the two begin to dissolve. We can no longer think of the plant without the animal and the animal without the plant. Normally we think of the plant and the animal that feeds on it as two separate organisms that interact. It is very hard, in fact, not to describe them in such terms. But we can ask the question, "Where do organisms end?" (See the article by that title in the Spring, 2000 issue of *In Context*.) Clearly, the milkweed is unthinkable without its animal associations, just as the animals cannot be described or understood without the milkweed. Milkweed's pollination is wholly dependent upon insects just as many insects are dependent upon milkweed for food and reproduction. Therefore, we must transcend the boundaries we construct when we look at an organism from a taxonomical standpoint. We can begin to see organisms as intersecting relationships that are part of the greater web of life. In the case of common milkweed this is especially evident, since even some of its physical substances (cardiac glycosides) remain unchanged as a part of various animal species.

From an evolutionary perspective we need to imagine that the lives of common milkweed and its specialist insects have been related to each other for a long period of time—going back to the mid-Tertiary in the case of the red milkweed beetle. They have co-evolved and have a history together—they belong to each other or are part of each other. One of the key realizations of an ecological-evolutionary perspective is that what appear today to be separate entities are in fact interconnected. As Rausher has stated, "The process of co-evolution between plants and their natural enemies—including viruses, fungi, bacteria, nematodes, insects and mammals—is believed by many biologists to have generated much of the Earth's biological diversity." That this diversity is an expression of the interconnectedness between life forms is what we begin to understand and to appreciate when we concern ourselves with the life histories of intersecting organisms.

Summarizing Picture

When you see an old field, the robust common milkweed plants stand out among the much sleeker grasses, asters, or goldenrods. Common milkweed has thick stems and expansive leaves that in shape and size look more like the leaves of a plant growing in shady woods than in a sunny old field. In the warm summer days of late June and through much of July, the large spherical heads of flowers unfold on the upper part of the stems. The individual flowers are actually quite large for a field plant and they produce large amounts of concentrated nectar. Their scent spreads out into the surroundings. When in flower, a colony of milkweeds attracts—day and night—a great variety and number of insects of all different shapes and sizes. For several weeks in summer milkweed becomes a microhabitat with a singular concentration of insect life.

The flower is highly specialized. Those parts of the flower that normally are in direct contact with the air and insects—the receptive stigma and the pollen grains—are encapsulated, the stigma within the stigmatic chamber that opens to the world only through a narrow slit, and the pollen grains in the pollinia, which themselves are hidden within the chambers. Pollination becomes an intricate process of removal and insertion that is unthinkable without the intervention of insects. Only they can bring the specialized structures into the precise spatial relation the plant needs for fertilization to occur.

While the flower outwardly displays milkweed's strong specialization in its form, all parts of the plant except the flowers produce the specialized latex sap. (The flowers produce, instead, a sugary nectar.) The latex sap is encountered by animals that feed on the plant. Small insects can become caught in the sticky sap. Others can be repelled by the cardiac glycosides in the sap, while still others incorporate the toxins into their own body. The life of these often vibrantly colored insects is in multiple ways closely bound up with the milkweed.

After the flowers wilt, the fruit pods begin to expand. While relatively few fruits form out of the multitude of flowers, those that do develop grow large—much larger than the fruits of other old-field community plants. The pods swell and orient themselves upward, a contrasting gesture to the globes of flowers. Each pod is full of seeds, seeds that are large and heavy. But they have the light feather-like extensions of the white comas that allow them to be carried away on a breeze when the pods split open. It is almost as if the upward pointing pods are prefiguring what is to come—the upward lift of the coma-bearing seeds that disperse into the larger environment. As with all stages of milkweed, both pods and seeds provide nourishment to insects.

One salient feature that informs milkweed is its exuberant and robust growth. Underground it spreads year to year, forming a network of thick rhizomes out of which the above-ground shoots grow. The thick shoots bring forth large, spreading leaves. All these parts of the plant contain the milky sap, which is continually produced as the plant grows and develops. A marked transformation in substance and form occurs as the many large umbels unfold in the summer light and warmth. As the stems and leaves are rich in milk sap, so are the flowers rich in sweet nectar. Both the leaves and the flowers attract countless insects; milkweed is of fundamental importance to the existence of some of these creatures. In the fall, large pods form, containing many large seeds that spread out into the environment.

Milkweed is effusive and yet it is also specialized. This specialization both attracts and repels insects. Think of the sticky, toxic sap that can also be protective, or the pollination process in which insects are attracted to the nectar, but may become injured or trapped by the flower structure. Milkweed invites life, but also holds it back. There is a fascinating tension in this plant.

NOTE: For the references to this article, see http://natureinstitute.org/txt/ch/milkweed.htm. Photos: Craig Holdrege.

An Unexpected, Submicroscopic Journey

Steve Talbott

It was in the fall of 2008 that Nature Institute director Craig Holdrege suggested I might like to look into what was happening in epigenetics. The term “epigenetics” was of course familiar to me—I had written a fair amount about genetics and genetic engineering. But my focus had always been very broad: what sort of view of the organism was driving geneticists; how was their work affecting our thinking and our public policy, for example, in agriculture and medicine; and what of the organisms themselves who were suffering this tinkering with the foundations of their existence? Diving into the immense technical literature so as to engage the issues at the level where molecular biologists were posing their precise and narrow experimental questions was not something I would ever have thought of doing on my own.

“Epigenetics” can be taken in the widest sense as referring to our understanding of how the organism makes use of its genes. It’s a matter of putting genes in their context—an effort that has gained tremendous momentum world-wide since Craig wrote his prescient 1996 book, *Genetics and the Manipulation of Life: The Forgotten Factor of Context*. So it was this *context*—which means, I eventually reminded myself, *just about everything*—that Craig so casually suggested I look into!

Fortunately, I didn’t fully consider the scope of the task at the time—the thought probably would have paralyzed me—and in January, 2009 I dug into my first pile of technical literature. Sensibly, given a vivid awareness of my own limitations, I focused initially upon those cellular processes most directly involved in gene regulation. And immediately the surprises began.

In the first place, it needs saying that I am no molecular biologist. In fact, I am not a biologist at all. Yet in some ways—and this was my initial surprise—I found the literature, for all its challenging technical aspects, oddly familiar and accessible. It didn’t take me long to figure out why: the researchers whose reports I was reading were treating DNA and genetic processes with the mindset of computer engineers. The mechanistic logic they were trying to elucidate was not at all unlike the kind of logic I had had to deal with for many years when I worked for computer manufacturers. DNA, as everyone knows today, is commonly regarded as the bearer of a digital “code” or “program.” The way researchers were explaining its role in the cell was scarcely different from the way I often had explained how software and hardware works.

Another surprise had to do with how slow the media outlets were to pick up on what was happening. My familiarity with computer engineering enabled me quickly to recognize how remote from computation were the actual phenomena the molecular biologists were trying to describe. Their language may have been engineerese, but the reality obviously had little to do with any logic of engineering. And, at some level, the researchers themselves have seemed to realize during the past decade that they are engaged in a revolutionary transformation of their field, even if their language and many of their working concepts remain “old-school.” No one reading the literature today with a receptive mind can fail to see that a great deal of our understanding of genes and organisms is being turned inside out and upside down.

Puzzlingly, however, almost none of this extraordinary *significance* of the research was making it into the popular media. Encountering one remarkable finding after another, I began wondering why I had previously heard almost nothing of the drama taking place in the molecular biological laboratories. The emerging picture of the organism had little to do with the tired, same-as-always images conveyed in the press—images of genes mechanistically orchestrating the life of the cell and organism. I was daily reading dense technical reports suggesting the need for a much more vivid and living understanding of the organism—reports in which the researchers themselves often expressed a sense of excitement about the almost overwhelming pace of their new discoveries and about the changes required in their ways of thinking. Wouldn’t the science reporters for, say, the *New York Times*, want to play a leading role in exploring the implications of all this—and in keeping the general public informed?

In the end, I was fully sucked into the research and decided I could at least do my own part in presenting the ongoing discoveries to a wider audience. This led to four rather lengthy and technical essays in The Nature Institute’s online newsletter, *NetFuture*. These in turn have helped produce opportunities I could scarcely have imagined before my research began:

- I was asked to give a presentation to a gathering of molecular biologists, ethicists, philosophers, and social scientists at the Hastings Institute in the lower Hudson Valley of New York. The conference was focused on synthetic biology, the discipline where researchers try to attack the problem of synthesizing simple organisms from scratch. I spoke to a very attentive and engaged audience about the picture of the organism emerging from molecular biology today, which is a picture far removed from the one in the minds of those who are currently imagining they can craft an organism by assembling a collection of parts.

- A book containing articles offered as a festschrift to Harvard biologist emerita Ruth Hubbard (author of the classic *Exploding the Gene Myth*) is currently in preparation, edited by Sheldon Krimsky of Tufts University. Hubbard herself, along with her Harvard colleague, Richard Lewontin, are advisers for the project. Quite unexpectedly, I was invited to submit a chapter for the book—a chapter that survived the initial review process and has been accepted for inclusion in the book, pending approval by the eventual publisher.

- One consequence of my sending that paper to a few qualified people for criticism is that I received a request to contribute a separate paper for the journal, *Studies in History and Philosophy of Science* (Part C, Biological and Biomedical Sciences). This paper, more than anything else I have written, focuses on what you might call the *inwardness* of all organisms—the directed, meaningful, expressive, and non-mechanistic character of their lives, as borne out by work in molecular biology.

- *The New Atlantis*, an influential journal dealing with science, technology, and public policy, is committed to publishing a series of my articles dealing with the revolution in molecular biology and its broader implications for science and our understanding of the living organism. The editors, having become convinced of the importance of this project, and wanting their publication to take a leading role in public education, plan to promote the articles as widely as possible. *The New Atlantis* goes to all congressional offices as well as to numerous government officials, policy makers, think tank scholars, and many others, in addition to its regular subscriber list. It also maintains a stimulating website where its contents are available to the public (thenewatlantis.com). The first article in the series will likely have appeared by the time you read this.

- Finally: just as this article was being readied for press, I received an invitation to contribute a chapter to a book dealing with the ethics of synthetic biology. The book is being prepared by the Hastings Center (see first bullet item above) as a follow-up to its conference and in recognition of the fact that today there is "considerable interest nationally in the ethics of synthetic biology."

To have such opportunities fall in one's lap is a little unnerving for someone with no extensive background in biology! But, on the other hand, the biological sciences seem to be moving, however clumsily and however unconsciously, in a direction fully vindicating the contextualizing stance Craig took up in his 1996 book, which is very much the stance I, too, have assumed. It's comforting—if also more than a little dangerous—to feel that you have history on your side!

What follows is a brief look at one of the latest pages in this history.

Assessing the Human Genome Project

Back in July 2009 (in *NetFuture* #177), I ventured the prediction that, "within a year or two some highly placed researcher, secure enough in his or her position of authority to take the risk," would publish a dramatic statement to the following effect:

> *What are we doing?* Every month we gather more data on the genome and epigenome in an ever-rising flood. We learn more and more details about more and more minute processes, and the dizzying pace of discovery provokes use of the word "exciting" in one technical paper after another. But has no one noticed that we seem to be getting farther and farther away from an understanding of cell and organism?
>
> We used to have a clear framework for saying what made what happen. DNA gave us a blueprint or instruction book or program as a First Cause to which everything else could be traced. At the head of the chain of causes was a single set of crystal-precise molecules, and further on down the line was everything else we see in the living organism.
>
> That instruction book, however, has disappeared. What is there to take its place? The satisfyingly clear lines of cause and effect are, with every exciting new discovery, dissolving further into a chaos of causal arrows pointing in all possible directions. Where are the higher-level ordering principles? Yes, we clearly are gaining countless useful facts, but is there anything causal, anything explanatory, holding these facts together in the way that the organism itself so obviously holds together?

It was, of course, rash to predict a single, dramatic outburst of this sort. While I still think such an event entirely possible, I would have done better to focus on a near-certainty: the radical implications of recent molecular researches, corrosive of so much prevailing thought, will progressively dawn upon the more open and flexible biologists and will even begin to be voiced in mainstream technical journals. In this connection I was struck by a recent collection of articles in *Nature* celebrating the tenth anniversary of the completion of the Human Genome Project.

If a single theme runs through all these articles, it is the contrast between the almost unbelievable technical sophistication of our data-collecting tools, on the one hand, and our incomprehension of the data, on the other. "Never before has the gap between the quantity of information and our ability to interpret it been so great," writes one group of authors (Khoury, Evans and Burke 2010).

In their introduction to "The Human Genome at Ten" the editors of *Nature* refer to the "mismatch" between the "rapidly increasing ease of gathering genomic data versus the continuing difficulty of establishing what the genetic elements actually do"—a sentiment put in stronger terms by James Collins, a bioengineer at Boston University: "We've made the mistake of equating the gathering of information with a corresponding increase in insight and understanding." (quoted in Hayden 2010).

Likewise *Nature* columnist Philip Ball, citing newer data-gathering projects such as an expensive initiative to solve protein structures, counsels restraint: "Before animal spirits transform this into the next 'revolution in medicine', it might be wise to ask whether the Human Genome Project has something to tell us about the wisdom of collecting huge quantities of stamps before we know anything about them" (Ball 2010).

And finally, mathematical biologist Joshua Plotkin, referring to the discovery of vast regulative processes bearing on DNA, concludes: "Just the sheer existence of these exotic regulators suggests that our understanding about the most basic things—such as how a cell turns on and off—is incredibly naïve" (quoted in Hayden 2010).

The Frustrating Search for Cures

The strongest selling point for the Human Genome Project was that it would lead to numerous cures for diseases. And one of the most striking realizations to emerge from work of the past decade is that the link between any particular genetic feature and any particular complex trait—including most traits of interest—is extremely tenuous. This is true even of highly heritable traits. For example, although human height has about an 80 percent heritability, the top 20 gene features influencing height explain only about 3 percent of the variation from one person to the next. The same is true of most diseases. In all the relevant studies, as Emmanouil Dermitzakis and Andrew Clark observe in *Science*, "the magnitude of genetic effects is uniformly small":

> The lesson is that we do not yet fully grasp the genetic architecture of complex disorders in humans, and we will not be able to make accurate individual predictions of risk until we do. Predicting individual risk of complex traits is a tall challenge, in part because of the context-dependent way that the genotype manifests its effects on disease risk.

Dermitzakis and Clark go on to remark on the deceptive quality lent to genetic studies by reliance on "model organisms" in laboratory settings. Several gene variants in fruit flies have been precisely mapped to specific effects on the number of bristles on the fly, yet "those same variants within a natural population have little bearing on bristle counts."

Difficulties persist even when one starts with natural populations. While genome-wide association studies (GWAS) have turned up hundreds of mutations that can be statistically correlated with various diseases and traits, their biological relevance remains to be demonstrated, and they typically lead to no diagnostic or therapeutic benefit. For example, "a recently published 12 year follow-up study of cardiovascular disease in more than 19,000 women found that the 101 [genetic features] identified by GWAS as risk variants for cardiovascular disease did not predict cardiovascular outcomes" (McClellan and King 2010).

The difficulty of finding genes to "account" for traits is especially difficult in the study of cancer. Compare a tumor tissue with a normal tissue in the same individual, and you will find a remarkable number of genetic differences. For example, one study of an African woman with metastasized breast cancer revealed a total of 27,173 point mutations in the primary tumor and 51,710 in a metastatic tumor. "The difficulty," according to Bert Vogelstein, a cancer researcher at the Ludwig Center for Cancer Genetics and Therapeutics at Johns Hopkins, "is going to be figuring out how to use the information to help people rather than to just catalogue lots and lots of mutations" (Ledford 2010; Ding et al. 2010).

All of which has led many researchers to search for key mutations that are primary "drivers" as distinct from "by-products" of cancerous conditions. And one way to do this is to look for clusters of mutations that affect the same key biological processes—say, a particular signaling pathway—which in turn might be functionally related to the cancer of interest. Such mutation clusters, it is thought, should contain the truly causal genes.

The problem is not only that many "drivers" seem to occur at an extremely low frequency—say, in less than 1 percent of cancers—making risk prediction or causal explanations in individual cases extremely difficult. It's also that the processes affected by particular genes tend not to be well-defined and restricted, but rather merge seamlessly with the wider life of the cell and organism. A gene might play into any given process via innumerable direct and indirect routes. "We tend to talk about pathways and processes as if they are discrete compartments of biology," write Dermitzakis and Clark. "But genes and their products contribute to a network of interactions"—and these interactive networks "differ radically among tissues."

It is certainly reasonable to look for key points of influence where therapeutic intervention might prove most profitable. But the message of current work in molecular biology seems to be that, if we want to get our bearings amidst all the interacting variables, we should de-emphasize the search for neat and precise causes. We need to take in a larger picture, alert to coherent patterns and qualities that play throughout an organism. And whether we have any chance of succeeding in that task solely by burying our heads in molecular-level processes is a live question. Further, even when we do come face to face with a larger picture, we'll never *see* it except by looking at least partly with a qualitative and aesthetic eye. You will never "get" Da Vinci's *The Last Supper* if you are content with a mathematical analysis of pixels. Nor will you see the Taj Mahal if your engineer's eye notices only joints, beams, and fasteners.

If a playwright, having decided that the first draft of a play was too "bright" or "optimistic," should undertake to give it a rather darker or more tragic feel, we would expect the final drama to be changed throughout—perhaps more obviously in some places, but also very subtly in many others. One could not effect the transformation merely by inserting a "causal" sentence here or a revised stage gesture there. That's how it is with organic structures, whether works of art or organisms. So it is perfectly reasonable to assume that when a disease such as cancer overtakes a person, the difference will have to be recognized in qualitative changes potentially coloring everything in body and psyche.

It may be hard to imagine contemporary molecular biologists being reconciled to such a view. But acknowledgments of ignorance such as we heard above are a healthy start. One hopes that, coming as they do after a half-century of extraordinary—sometimes almost arrogant—confidence that molecular biology was laying bare the "mechanistic" secrets of life, the professions of ignorance will prove cathartic and signal an openness to new beginnings. The implosion of the gene-centered model of the organism should, after all, raise questions at the most fundamental level. What is the nature of the organism, and what distinguishes biological explanation from explanation in the physical sciences?

The articles in that special *Nature* collection did not lack for expressions of optimism. The sense of being at an impasse or an important turning point is certainly not universal among molecular biologists today, and perhaps not yet even widespread among those bench scientists busily gathering data and testing extremely narrow hypotheses. But, nevertheless, an awareness of an uncommon need for change and for receptivity toward new insights is, I think, the current "cutting edge" of biology. And the amazingly powerful research tools now in the hands of researchers will guarantee a stream of surprises that can only continue disturbing old dogmas.

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Events at the Institute

Depending on when you receive this newsletter, the following events at The Nature Institute may still be forthcoming:

- “Monday Nights with the Stars,” with Henrike Holdrege (November 8 and 15, 8 pm). Orient yourself to the night sky. Learn about the monthly and yearly rhythms of sun, moon and the planets. Look up to the stars with deepening knowledge and wonder.
- “The Spiritual Origin of Holistic Science in Goethe’s Life,” a talk by Johannes Kühl (November 22, 7:30 pm). Johannes is a physicist, researcher, and teacher. He is the director of the natural science section at the Goetheanum in Dornach, Switzerland.
- “Linear Perspective,” a three-part workshop with Henrike Holdrege (November 30, December 7 and 14, 7:30 to 9 pm). We will explore the laws of linear perspective by drawing, by studying works of art, and by practicing the principles of central projection. And we will work with the question whether perspective is a visual experience or relates to other senses.

Past events

Teachers’ Course: Bringing Science to Life

During the hottest week of the summer, 15 science teachers from the U.S. and abroad worked together at The Nature Institute. Each morning began with explorations of air, led by Henrike. Through the experiences and experiments we grappled with the elusive qualities of air. We learned firsthand how in experimentation we usually deal with the air of enclosed spaces, and that many of our concepts about air were developed in relation to “enclosed air” and not to the free, wafting, ever-changing, ambient air that is present in the world at large. It became clear how important it is to be wakeful and discerning when we interpret phenomena—that we do not simply import concepts formed in one area (usually that of the solid, in which we are so at home) into another.

The daily seminar with Jon McAlice showed how breathing—in its physiological and psychological aspects—lies at the heart of learning. Breathing is eminently an activity that encompasses polarity; without the movement between poles there is no breathing: going out, taking in; giving off, gathering in; lightness and weight. In learning there is a kind of breathing in the relation between going out in perception and taking in when we form concepts of things. We also have feelings that are more inward and others that expand outward; or think of the lightness of a humorous story counterbalanced by the weight of a tragic occurrence. And of course, breathing as a respiratory function enlivens our metabolism and mediates our relation to the external world. It became clear through this seminar how important it is that teachers become aware of the breathing process in learning and continually ask themselves: are things moving in dynamic ways in my classroom or am I perhaps—in the mode of instruction—all too focused on the one-sided view that learning has mainly to do with giving out information.

The afternoons found participants in different subject-group seminars that were followed by presentations by individuals. For example, we experienced how one can make visible the subtle movements of air that arise anytime a body is heated up or when gases of different nature interact, and we heard about the way a teacher works to bring the students to an experience of “gestures” in nature—the unifying qualities that shine through a plant or other organism.

Other events

- Henrike gave a talk on October 1 about “The Colors of the Rainbow and Magenta—200th Anniversary of Goethe’s *Theory of Color*.”

Participants of the 2010 “Bringing Science to Life” Course

◆ In late August a group of young adults involved in a "Community Lab" project of the organization Think Out-Word came to The Nature Institute. During an afternoon they helped on the grounds, and some of the participants experienced for the first time the joy (and hard work) of scything. The next day Craig and Henrike met with eleven of the participants. We told them about the work of The Nature Institute and let them experience something of that work through the activity of assembling mammal spines. We then asked them to help us understand what young adults are looking for and how The Nature Institute could serve that search. A fascinating conversation ensued. They expressed how many young people are interested in research, but don't necessarily have a clear picture of what exactly they mean by that term. There is a yearning to deepen experience in a methodical way—that is certainly a key feature of research. How could The Nature Institute provide opportunities for young adults to learn about and be guided through the process of doing research? Could this happen through internships, or through short courses that would be the starting point for a mentored research project? This conversation was just a beginning, and one we plan to continue.

Out and About

◆ In October Craig and Henrike traveled to São Paulo, Brazil. Craig participated in a symposium on *Goethe's Morphology* at the Biosciences Institute of the University of São Paulo and gave a talk on "Goethe's Delicate Empiricism: What Is Its Significance for Understanding Nature?" Then Henrike and Craig gave a four-day course at the University of São Paulo, sponsored by the Institute for Psychology, on "Holistic Knowing—A Practical Introduction," followed by a public weekend workshop on "Transformation in Nature and in Human Knowing: Developing Living Thinking."

◆ From July 19 to July 23 Craig and Henrike co-taught a course at Rudolf Steiner Institute in Easton, Massachussets. The topic was "Living Thinking through Plant Study and Projective Geometry." With active contributions of the fifteen participants we were able to discover and articulate essential features of concrete, life-filled thinking.

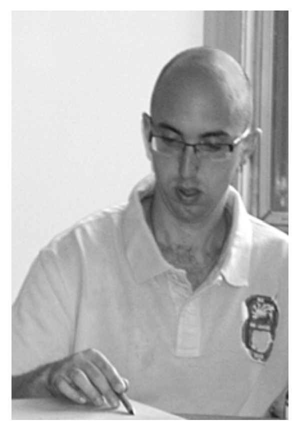
◆ The Hudson River Fellowship is a summer painting academy in the Catskill Mountains that is attended by talented young artists from around the country and from abroad. It aims to "give much needed direction to a new generation of painters. The Fellowship staff invited Craig and Henrike in July to engage in different activities with the students.

Craig led a guided walk up through the Kaaterskill Clove to the Kaaterskill Falls. After giving a brief overview of the clove's geological history, he pointed out the different types of trees and shrubs that grow along the clove and how their growth forms change depending on the microhabitat. The students—who are skilled in observing but often don't know what they are observing or give much thought to the environmental contexts—were full of questions and grateful to get to know a place where they would be painting during the weeks to come.

Henrike gave a workshop on "Transparent Media and Images," followed by an evening lecture on "The Colors of the Rainbow and Magenta." In awareness of the two hundredth anniversary of the first publication of Goethe's *Theory of Color*, she used some of Goethe's key discoveries as a foundation for explaining the Goethean color wheel. Drawing further on the work of Michael Wilson, she spoke about the polarity between green and magenta.

Studying Goethean Science at The Nature Institute

A report by João Felipe Toni



Joao contacted Craig in the spring to see if would be possible for him to do a guided study at the Institute to learn more about, and to experience, the Goethean approach to science. He was already familiar with the methodology and was eager to work with it more intensely. He arrived at the beginning of June and left in early August. Here is what he writes about his experience:

In 2003, at 21 years old, I was introduced to the works of Johann Wolfgang von Goethe and Rudolf Steiner by way of Thomas Göbel at the University of São Paulo. The teachings of this wise and choleric gentleman deeply influenced how I dealt with the issues that arose throughout my undergraduate studies in life sciences and science education. One of these issues concerned how botany has been taught in high schools and colleges. So I decided to immerse myself in Goethe's botanical writings, especially *The Metamorphosis of Plants*, and last year (2009) I presented my final project under the title, *Goethe´s Plant Morphology: Contributions of the History of Science to Botany Teaching*.

In order to expand this research and go deeper into Goethean science, I came to The Nature Institute in June for an internship, and I was privileged to study and work there for the whole summer.

In addition to a guided study program with Craig Holdrege, I participated in the two summer courses, and I worked in the library, garden, and on the grounds. In our weekly seminars Craig and I pursued readings in Goethe's botany, discussing these as well as the structure of my future dissertation. A particularly valuable discussion concerned the meaning of the phenomena of disunion and anastomosis in plants (polarity) and the physiological explanation of the refinement of the sap (*Steigerung*).

The two courses were also fruitful. In the first one Henrike Holdrege taught us how we can develop our imaginative thinking through projective geometry exercises. And together we worked with "exact sensorial imagination," explored by Craig with plants and vertebrae of mammals, and by Nathaniel Williams with artistic exercises. These activities provide an integrated methodology for the researcher of living forms. In the second course, one of the themes that drew my attention, offered by Jon McAlice, dealt with the role of breathing and rhythm in learning and teaching. The moment that we saw the functioning of a real pig's lung was impressive also.

All this while I was making my own observations of plants and carrying out independent research activities relating to the work of Jochen Bockemühl. I began with the comparative morphology of different individuals of *Ranunculus acris* (buttercup) in different environments (roadsides, meadows, and woods), and I also compared different species of the larger buttercup family (Ranunculaceae). Grohman´s book, *The Plant*, and the article "Gestaltmotive in der Gattung *Ranunculus*" by Andreas Suchantke were very helpful for this purpose.

I want to thank Stijn van Tongerloo for helping me with the translation of the German article. In a second activity I did drawings, observations, and a survey of the plant community of one of the meadows of the Hawthorne Valley Farm. And finally Stijn and I studied the morphology of the different species of Asteraceae or Compositae (Daisy family), with special attention to the transition from the leaf series to the bracts of the inflorescences and to the perianth of the tiny flowers of this family. The genera Centaurea (Knapweed) provided a particularly interesting example of this transition. We dried leaves for plant posters in order to document these studies. I also want to thank all The Nature Institute's staff (Craig and Henrike Holdrege, Steve Talbott and Gloria Kemp) for making this experience possible.

Gloria Kemp Retires

Gloria began working for The Nature Institute in the fall of 2005. In these five years she has managed the office and outreach work for the Institute. However, those two words hardly do justice to the variety of work she actually carried out. When people signed up for a course, Gloria helped them find a place to stay that suited their needs. How many times did we hear how pleasant it was interacting with Gloria to make arrangements for a visit to The Nature Institute! Many of you will have met Gloria through the thank you notes that she sent to you when you gave a donation, or perhaps you have enjoyed the refreshments she prepared for our events. Gloria brought a personal and friendly touch to everything she did.

When Gloria came to the Institute, little did she know that she would be deeply involved in producing our flyers and brochures. She patiently learned how to navigate in PageMaker, teaching herself all she needed to know. She also was our database steward.

On any given morning Gloria had myriad tasks to accomplish and not the least achievement was her ability to shift from one activity to another at a moment's notice. Many were the times I disturbed her by adding to the list of things needing to be done.

Thank you, Gloria, for being such an integral part of our efforts, serving the mission of The Nature Institute in such a selfless way! —Craig Holdrege

Holistic Science Journal

The first issue of a new publication, *Holistic Science Journal*, has recently appeared. The founding editors, who are associated with Schumacher College in the UK, asked Craig Holdrege to be a consulting editor for the journal. Since he feels deeply aligned with the intent of the journal, he gladly took on the task. The editors write: "Holistic science concerns itself with the rigorous and integrated exercise of the full capacities of the human psyche in order to develop a deeply and truly participative relationship with nature. In going deeply into the nature of the phenomena, holistic science is able to appreciate the unity that is the source of the subtle differences."

To view the contents of the first issue and to subscribe to the journal, visit : http://www.earthlinksall.com/journal.htm.

2010 Public Summer Course

Transformation in Nature and in Human Knowing

Through the activities of projective geometry, plant study, and drawing we—the 13 participants and three teachers—encountered phenomena of transformation from many different perspectives. We constructed geometrical transformations that led us to the infinite and back again; we considered the transformation within individual plants and in the relation of different plants to one another; we drew transformations based on our plant observations; we put together the spines of different animals and saw how the same principle was modified in the different species; we compared skull forms. In these and other ways our understanding of transformation became more differentiated and saturated during the week. By the end of the week we could fill out the series of concepts: change – transformation – metamorphosis – development – evolution, with new and concrete meaning. We all felt that we had touched the real mystery of evolutionary processes and recognized how our typical ways of thinking about them do not begin to do justice to the intricacy of the phenomena themselves.

One participant described in detail how she experienced the week:

> I experienced transformation in myself as the week progressed, as I felt the "generative potential" [that we had discussed] "flexing its muscles"—expanding into the world until the world came to me. These words I write have been said before; I've heard them; I've read them, but this week I *experienced* the process over and over again as transformations expressed in other forms of life. Starting the day with projective geometry is an exercise that opens my mind and being to potential. By midweek, I was seeing life in geometric movements and seeing geometry in life.
>
> The Penstemon [plant study] showed me that I can come to know other organisms by entering their formative process. The activity with the vertebral columns demonstrated that this knowing can happen with different forms of life. Life comes to life. It comes to me and I come to it. Livingness reveals itself in the forms, but only if you actively follow them.
>
> When I read these ideas in books, they only go so far. When we do this work, it goes deeper. I seem to be living the stepwise process, from unknown to known and then another unknown comes in. So the doing with your guidance is a necessary part of learning for me. The conversations and other perspectives from the different participants also contribute to this building and expanding process.

A Ph.D. in Sustainability Education

The Relevance of The Nature Institute's Adult Education Work

On May 22, 2010, Craig Holdrege received a Ph.D. in sustainability education from Prescott College. Craig had entered the program in August 2006 and received a Presidential scholarship that paid the tuition for the four years. The program is designed for adult learners who bring life and professional experience into the program with the expectation that it will culminate in a dissertation that is both scholarly and practically relevant to the issue of sustainability and education. In this program Craig was able to broaden his understanding of the many approaches to creating a more sustainable world, and study how a variety of thinkers and practitioners articulate the ways in which education can evolve to encompass the needs of the planet as a whole. At the same time he brought the Goethean approach to science and the work of The Nature Institute into relation to the sustainability movement.

For his dissertation he chose to focus on the adult education work of The Nature Institute as a unique form of adult learning that addresses root causes of our unsustainable relation to the world. He elucidates the modern ingrained habit of thought that treats the world as an assemblage of "things," a perspective that creates distance between us and the rest of the world. He argues that we need to move from this kind of "object-thinking" to a living thinking modeled after the dynamic and contextual nature of life. Drawing from the wealth of experience gained in teaching Nature Institute summer courses for the past seven years, he shows how he and his colleagues work to help adult learners begin to make this shift. He illustrates in great detail how plant study using a Goethean phenomenological method can help people to learn about and internalize essential qualities of life such as transformation, context-sensitivity, and dynamism. He makes the case that a more health-bringing and resilient relation of humanity to the rest of the planet will depend on our ability to increasingly embody living thinking.

The question arises whether such a way of learning is actually effective. Craig designed a survey that he sent to all participants in Nature Institute courses between 2002 and 2008. Half of the participants answered the survey. One substantial chapter of the dissertation is dedicated to the analysis and discussion of the survey responses. They give an impressive picture of how Nature Institute courses, despite their short duration (usually a week) can have significant impact on a person's life. For example, he asked whether the experience at The Nature Institute had affected the participants' professional work. Eighty-one percent of respondents answered "yes." Here are a few of the responses:

> *Profoundly. I am aware of something that previously I never knew existed. I can't imagine teaching without knowing that there is another way to look at the world than the one that I learned in college and in my previous profession. I work toward figuring out how to show my students these other, more intuitive ways. This requires them (and me) to carefully, objectively observe without predrawn conclusions and then to thoughtfully find connections that can continue to grow and change.* (Former project manager in the computer industry, currently high school science teacher)

> *Yes, as a gardener and landscaper [I found that] the course has helped me to visualize and shape the man-made landscape in more harmonious ways, blending them into the natural environment.* (Stonemason, landscaper)

> *Yes, my perception in diverse situations with people I see in my practice as a pediatrician increased a lot.* (Pediatrician)

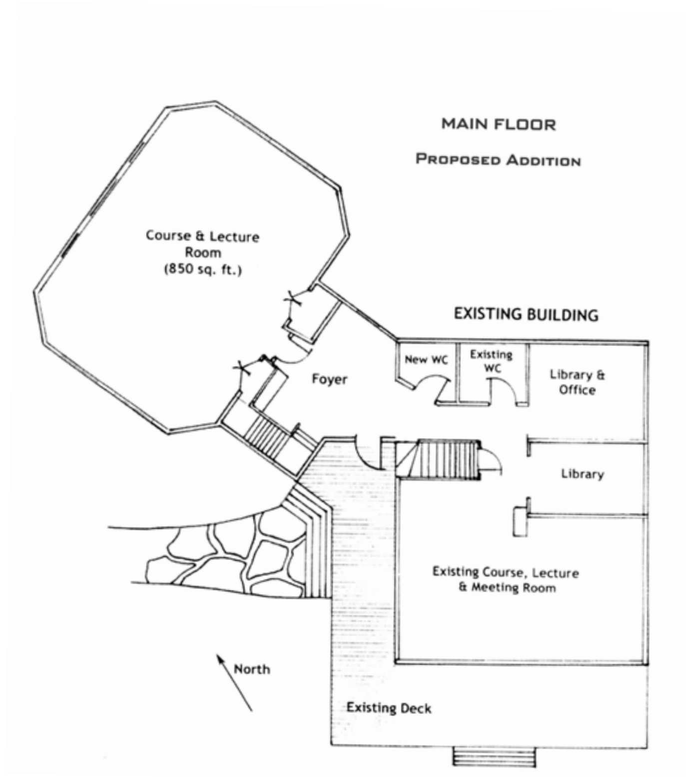
> *In the Nature Institute course, I was able to experience, reflect, integrate, and express the complexity and beauty of the relationships of an ecosystem and the growth processes of a plant. This has been invaluable in my understanding of natural living systems and the qualities of adaptation and flexibility that they reflect. By understanding these qualities in nature, it helped me to tap into these qualities in myself. Developing these qualities in myself has allowed me to cope with new situations and challenges in creative ways.* (Sustainability and gardening educator)

> *Truthfully, it is hard to completely know overall how this work has impacted my professional life, because it does not just change one piece; rather it changes your way of seeing and approaching and thinking about things—it just becomes a way of thinking. Once you are conscious of taking as much as possible into account, it becomes a thinking habit that really permeates how you approach everything.* (College biology professor)

Participants in our courses and workshops often ask afterwards: Have you written anything about this work that could support my further explorations and practice of the approach? The answer until now was "no." With the dissertation behind him and with it as a foundation, Craig is currently working on a book, *Developing Living Thinking—A Practical Guide*, which he hopes will fill this void.

The Nature Institute Is Growing

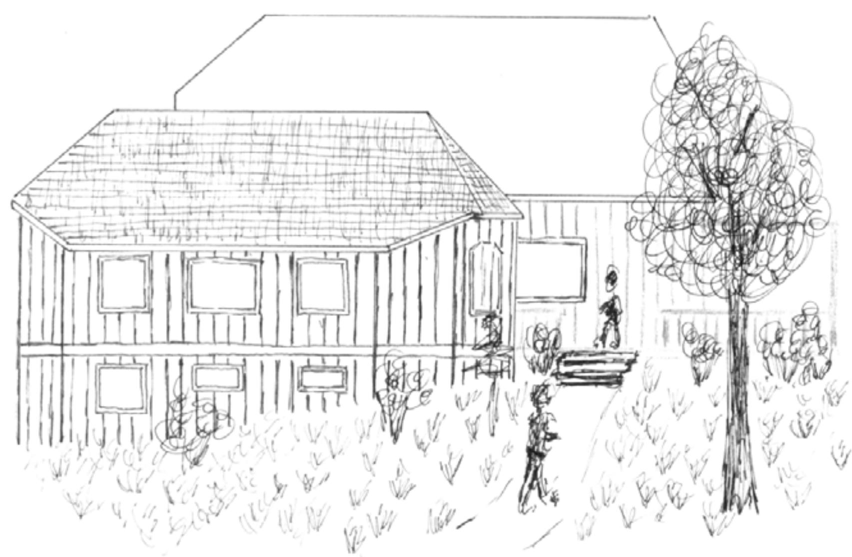
For some time we have known that we need to expand our facilities. Our lecture and course room is a lovely space—but only for smaller gatherings. Often it is cramped and overcrowded during events. Moreover, we are currently using every nook and cranny in the rest of the building. It cannot house any expansion in staffing or activities. Since we add new programs each year and want The Nature Institute to become a place where more people can come to work, study, and learn, an expansion of our facilities is essential.



At a special meeting of our Board of Directors last May—which followed a weekend colloquium in April on "The Nature Institute: Past, Present, and Future"—the board decided to start a capital campaign for a building project with the goal of breaking ground in May 2011 and project completion in early winter 2012. We will add a 2,000 square foot wing to the existing building that will provide us with a large course and lecture room, additional research, lab and office spaces, as well as gathering spaces for our events. We plan to build a beautiful, but modest and energy-efficient structure, and we will also make the existing building more energy efficient.

With the able guidance of Nature Institute friend Heide Zajonc, we began a capital campaign in October. We are also in the fortunate position to have a leadership gift in the amount of $150,000 from the Seyhan Ege Trust—these funds come from a bequest left to us by Seyhan Ege. The total project budget is $375,000. We therefore need to raise a total of $225,000 in the capital campaign.

All *In Context* readers have received information about the campaign and an appeal. Some of you have already sent in a gift or made a pledge. Early pledges totaling $100,000—what a great start to the campaign!—make us confident that we can reach the $225,000 campaign goal.



PROPOSED ADDITION - View From Northwest

The broad support of our friends with contributions large and small will make this campaign a success. In case you have not yet contributed and would like to, we have included a donation envelope in this issue. We will keep you informed about our campaign progress and further details of the building project.

Thank You !

Our heart-felt thanks go out to all of you who have contributed money, services, or goods to The Nature Institute between April 1, 2010 and September 30, 2010.

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Nancy Kay Anderson
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IN MEMORY OF
YVONNE CURTIS-STARR

Susan Starr

A PLACE FOR MEMORIES

Long-time Nature Institute friend and supporter, Susan Starr, offers this thought for those who have lost a loved one:

Not long after the passing of my mother, I began making donations to organizations in memory of her. Somehow, the idea that she was now viewing, with new interest, the activities relevant to our times kept coming up for me. Having been a donor to The Nature Institute since its beginnings, I sent a Memorial Book and a donation in memory of her. A parent in my kindergarten is a book binder, who bound a beautiful book with many blank pages for others to use. The In Memoriam book now resides in the office of The Nature Institute.

If you would like the name of someone who has passed away inscribed in this book, along with a brief memorial tribute you supply, please contact us.

The Experiment as Mediator of Object and Subject

Johann Wolfgang von Goethe

As soon as we perceive the objects around us we consider them in relation to ourselves—and rightfully so. For our entire fate depends upon whether they please or displease, attract or repel, benefit or harm us. This completely natural way of considering and judging things seems as easy as it is necessary. But it also makes us susceptible to a thousand errors that can shame us and embitter our lives.

Those human beings undertake a much more difficult task whose desire for knowledge kindles a striving to observe the things of nature in and of themselves and in their relations to one another. We no longer have the standard that helped us when we looked at things in relation to ourselves. We lack the measure of pleasure and displeasure, attraction and repulsion, use and harm. We must renounce these and as quasi-divine beings seek and examine what is and not what pleases. True botanists should not be touched by the beauty or the utility of a plant. They should investigate the plant's formation and its relation to the remaining plant kingdom. Just as the sun coaxes forth and shines on all plants, botanists should consider all plants with an even and quiet gaze and take the measure for knowledge—the data that form the basis for judgment—not out of themselves but out of the circle of what they observe.

The history of science teaches us how difficult this renunciation is. How we come to hypotheses, theories, systems, or whatever other modes of thought may exist through which we try to grasp the infinite, will be the topic of the second part of this short essay. In the first part I will consider how we proceed when we aim to understand the forces of nature. My current studies of the history of physics often provide the opportunity to think about these matters and give rise to this little essay. I strive to show in what way many great individuals have furthered, and also harmed, science.

As soon as we consider a phenomenon in itself and in relation to others, neither desiring nor disliking it, we will in quiet attentiveness be able to form a clear concept of it, its parts, and its relations. The more we expand our considerations and the more we relate phenomena to one another, the more we exercise the gift of observation that lies within us. If we know how to relate this knowledge to ourselves in our actions, we earn the right to be called intelligent. For any well-constituted person, who is by nature moderate or has been made moderate by circumstances, achieving such intelligence is not difficult because life itself guides us in every step. But when as observers we use our strict power of discernment to examine nature's hidden relationships; when we enter a world in which we alone can guide our steps and must take care to avoid all haste; when we keep our eye focused on our goal and do not allow any useful or harmful circumstance to pass by unnoticed; when we are our own most critical observer, controlled by no other and remaining skeptical of ourselves despite all inner engagement—in all these ways it is evident how strict the demands are, whether on ourselves or on others, and how little we can hope to completely fulfill them. But these difficulties and the hypothetical impossibility of surmounting them must not hinder us from achieving what is possible. We will come farthest when we become cognizant of the means that have allowed capable individuals to expand science. And we will also delineate the false pathways that have been taken, pathways that a great number of students, sometimes for centuries, have followed until subsequent experiences brought observers onto the correct path.

It goes without saying that experience, as in everything we undertake, has and should have the greatest influence in science, which is my present topic of consideration. Nor will anyone deny the high—and as it were creative and independent—powers of soul that apprehend, collect, order, and develop these experiences. But how these experiences are to be gained and used, and how we can develop and apply our powers is not generally known or recognized.

As soon as phenomena catch the attention of individuals with keen minds, they are inclined to observe and are also astute in making observations. I have often noticed this during my studies of light and color in conversations with people unacquainted with this topic that interests me so much. When their attention was stimulated they noticed phenomena that I either did not know or had overlooked. They corrected ideas that I had formed too hastily, allowing me to make faster steps and to step out of the limitations in which an arduous investigation often captures us.

It is true here as in other human endeavors that only the interest of many focused on a single point will generate something excellent. The greatest obstacles for a researcher are the envy that would exclude others from the laurels of a discovery and the intemperate desire to consider and elaborate on discoveries only in one's own particular way.

I have been too satisfied with this method of working together with others to consider proceeding in any other way. I know exactly to whom I am indebted, and publicly acknowledging this in the future will be a joy to me.

If naturally attentive individuals can be of such help to us, how much greater the gain when those with training mutually aid each other. Any area of science is so vast that many individuals are needed to carry what one person alone cannot. We may notice that knowledge, like enclosed but living water, rises over time to a certain level and that the greatest discoveries emerge not only through people but also through time. We see this when important discoveries are made by two or more skilled thinkers at the same time. Just as we are indebted to society and friends, so are we even more indebted to the world and to the centuries. In both cases we cannot do enough to acknowledge how necessary it is that communication, mutual support, memory, and contradiction all play a role in keeping us on track and carrying us forward.

For this reason we should, as scientists, do just the opposite of artists: As artists we do well not to show our products to the public until they are completed, because no one can easily give advice or provide assistance. When the artwork is complete we can consider and take to heart praise or criticism, let them inform our experience, and then begin to develop and prepare a new work of art. In scientific matters, by contrast, it is useful to publicly communicate every experience, every conjecture. It is also advisable not to erect a scientific edifice until its plan and materials are generally known and have been judged and chosen.

We speak of an experiment when we take experiences of our own or of others, deliberately reproduce and present again the phenomena that arose, both those that came about fortuitously and those that appeared through the artifice of the experiment.

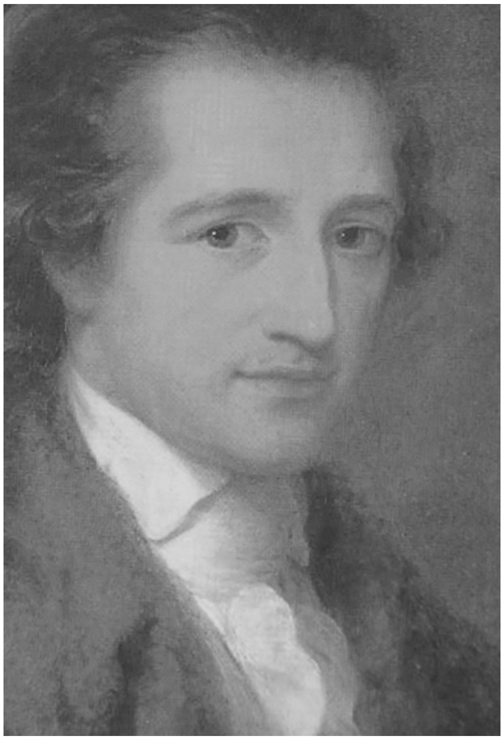
The value of an experiment, whether simple or complex, is that under certain conditions, with familiar apparatus and the necessary skill, it can be at any time reproduced as long as we re-create the same situation. Rightly we stand in awe of the human mind that can bring about the necessary constellation of circumstances and that is able to craft the instruments needed for experimentation. Such are being invented daily.

While we can praise a single experiment, it gains its true value only through its connection and unification with other experiments. Even to connect two experiments that are similar to each other demands more attention and vigilance than the keen observer might demand of himself. Two phenomena may be related, but not nearly as closely as we believe. Two experiments can appear to follow from one another and yet a whole series should lie between them to show the natural connections.

We cannot take great enough care when making inferences based on experiments. We should not try through experiments to directly prove something or to confirm a theory. For at this pass—the transition from experience to judgment, from knowledge to application—lie in wait all our inner enemies: imaginative powers that lift us on their wings into heights while letting us believe we have our feet firmly on the ground, impatience, haste, self-satisfaction, rigidity, thought forms, preconceived opinions, lassitude, frivolity, and fickleness. This horde and all its followers lie in ambush and suddenly attack both the active observer and the quiet one who seems so well secured against all passions.

To warn of these dangers, and to become more attentive to them, let me say something that may seem paradoxical. I dare to claim that one experiment, and even several of them, does not prove anything and that nothing is more dangerous than wanting to prove a thesis directly by means of an experiment. The biggest errors have arisen precisely because this danger and the limitations of the method have not been recognized. I need to express myself more clearly to avoid the suspicion that I am opening all doors to doubt: Every single experience, every single experiment through which we reproduce that experience, is essentially an isolated piece of knowledge and through carrying out the experiment a number of times we verify it as such. Within the same discipline we can know of two experiences and they can be closely related or can even be very closely related. Our tendency is to hold them to be more closely related than they are. This corresponds to human nature, and the history of the human intellect reveals thousands of examples and I myself have noticed that I make this mistake almost daily.

This mistake usually has its source in another, closely related one, namely, that we are often more delighted with the idea than with the thing itself. Or perhaps we should say: we take pleasure in a thing in so far as we form an idea of it and when it fits into our way of looking. We may try to raise our mode of thought so far above the everyday mode as possible and strive to purify it, but nonetheless it usually still remains only a mode a thought. It follows that we attempt to bring many phenomena into a certain graspable relation to one another that they may, looked at more closely, not have. And we have the tendency to form hypotheses and theories and to craft terminology and systems accordingly. We cannot condemn these attempts since they arise with necessity out of the organization of our being.



Goethe the Scientist and Self-Critic

This essay by Goethe was written in the spring of 1792. It is remarkable how prescient it remains over 200 years later—more than enough reason to publish it in a new translation. It would be hard to find an essay that describes so many of the key elements of a rigorous, experience-based, and phenomenological scientific methodology in such a short space. In many respects Goethe elucidates what one could simply call "good science": The phenomena themselves should always be the focus of attention and the intent is to let the phenomena in their manifold relations come as fully as possible to expression. This is, as Goethe recognized, easy to say and all too difficult to achieve. Good science entails a wakeful and critical attitude towards oneself, and Goethe shows how vividly aware he was of science as a human activity. Since we are involved in every aspect of a scientific investigation, we need to attend to the many "inner enemies" that can color and distort our view of things. And while Goethe appeals to a "divine" attitude in which we "seek and examine what is and not what pleases," he is also clear that we cannot do this by detaching ourselves and trying to find a point of view that transcends all points of view.

No, we must engage. But the engagement is not one of theorizing and model-making, but rather one of achieving rich and manifold experiences, for example by creating a series of experiments that contain an array of variations so that we begin to unveil the phenomena through a many-sided consideration. In this movement through the phenomena and their variations, an order can begin to appear and patterns or relationships show themselves that Goethe calls experiences of a higher order in this essay. This is a seeing of relationships—inner lawfulness—that arises out of the engagement with the phenomena. It is not a theory or hypothesis that one formulates prior to engagement as the lens through which one views all the phenomena.

When Goethe wrote this essay, he was researching color. He had published a first essay on *Contributions to Optics,* and a second one followed soon thereafter. In these studies he carried out numerous experiments, so that when he writes of experimentation in the "Experiment as Mediator of Object and Subject" he is speaking out of direct experience. Moreover, he was also studying contemporary literature on optics and color, which were rooted in the work of Isaac Newton, so that he had keenly in mind a theory-driven approach to science that he believed gave a skewed view of the phenomena themselves. His work on color and optics continued over the next two decades, culminating in his *Farbenlehre*, which was published in 1810—200 years ago. (*Farbenlehre* is usually translated as *Theory of Color*, but might be more accurately rendered as *A Discourse on Color.*)

The idea that science should be theory-driven and all experimentation hypothesis-based still dominates science today. In science education students often learn theories and models as if they were phenomena, and experiments are largely carried out to substantiate an idea. A kind of indoctrination occurs. Thankfully, there is now a movement towards what is called "inquiry-based" learning whereby students experience science as a process of exploration. It is precisely undogmatic and self-critical exploration, carried out in careful dialogue with the phenomena at every step, that Goethe urges. This little essay belongs in the hand of every scientist and every science teacher.

Craig Holdrege

On the one hand, every experience, every experiment is by its very nature isolated. On the other hand, the power of the human mind seeks to unite with tremendous force all that it meets in the outer world. Considering all this, we can easily see the danger of connecting an individual experience with a preconceived idea, or of wanting to prove by means of individual experiments relations that are not altogether sense perceptible — that the creative power of thought has already formulated.

Through such efforts, theories and systems arise that do honor to the acuity of their author. But when they find too much acclaim and are maintained longer than they should be, they restrict and are harmful to the very progress of the human spirit they at first supported.

We can notice that a good mind is all the more artful the less data lie before it. To show its command, it selects a few flattering favorites from all the available data and knows how to order what is left over to show no contradictions. It knows how to confound, enwrap, and push aside the opposing data, and in the end the result resembles a despotic kingdom rather than a freely organized republic.

Such a master of high repute finds no lack of admirers, and students who learn the history of the framework are awed by it and try as far as possible to make the master's way of thinking their own. Such a teaching can dominate to an extent that anyone doubting it would be found disrespectful and audacious. Only later ages would dare approach this holy of holies and vindicate healthy common sense by remarking of the founder of the sect what a humorous mind once said of a great scientist: he would have been a great man had he not been so inventive.

It is not enough to point to such dangers and warn of them. It is only right that we disclose our position and show in what way we or others before us have avoided a mistaken path.

I said before that I hold the direct application of an experiment to prove some hypothesis to be harmful. I also stated that I acknowledge the experiment as a mediator. Since this is the crucial point, let me explain clearly: In living nature nothing happens that is not in connection with a whole. When experiences appear to us in isolation or when we look at experiments as presenting only isolated facts, that is not to say that the facts are indeed isolated. The question is: how do we find the connections between phenomena or within a given situation?

I have pointed out that we are subject to error when we try to directly connect an isolated fact with our faculty of thought and judgment. In contrast, we accomplish most when we never tire in exploring and working through a single experience or experiment by investigating it from all sides and in all its modifications.

It warrants a future and separate consideration to show how the intellect can be of help on this pathway. Let me say only so much here: since everything in nature, especially the more common forces and elements, is in eternal action and reaction, we can say of every phenomenon that it is connected to countless others, just as a radiant point of light sends out its rays in all directions. Once we have carried out an experiment, we cannot be careful enough to examine other bordering phenomena and what follows next. This is more important than looking at the experiment in itself. It is the duty of the scientist to modify every single experiment. This is the opposite of what a writer does whose aim is to entertain. Writers who leave no room for roaming thought bore their readers. Scientists must work ceaselessly as if the goal was to leave nothing for future generations to accomplish. Nevertheless, they will be reminded that our intellect in no way encompasses nature and that no one has the ability to exhaust any one field of inquiry.

In the first two of my contributions to optics I presented such a series of experiments that border on one another and that are directly connected with each other. When we attain an overview of all of them we see that they constitute, as it were, one single experiment, one experience presented from manifold perspectives.

Such an experience consisting of a multitude of others is an experience of a higher order. It is like a formula through which countless individual computations can be expressed. I believe it is the duty of a scientist to work toward such experiences of a higher kind. The work of the best scientists in the field shows us this. When we place one phenomenon beside the next, or rather, when we develop the subsequent step out of what preceded it, we advance with a thoroughness learned from the mathematician. And even where we do not venture into calculations, we must proceed as if a strict geometer looked over our shoulder.

The circumspect and pure nature of the mathematical method reveals every leap in assertion. Its proofs are simply the expanded explication of connections that are already implicit in the more basic parts, showing in the sequence of steps that the whole is correct and unshakable. Mathematical demonstrations are therefore more of the nature of expositions or recapitulations than they are arguments. Since I have made this distinction here, let me look back:

We can see the stark difference between a mathematical demonstration, which connects basic elements, and a proof that a clever speaker devises out of arguments. Arguments can contain wholly isolated facts and nonetheless, through cleverness and imagination, make a point and create the surprising semblance of right or wrong, truth or error. Likewise we can compose individual experiments into an argument to support a hypothesis or theory, and generate a proof that, to a greater or lesser degree, deceives us.

If, by contrast, we want to work honestly with ourselves and others, we will attempt with great care to elaborate individual experiments into experiences of a higher nature. Individual experiments can be expressed in concise statements, placed side by side, and the more such statements we provide, the better they can be ordered and brought into a relationship that is as unshakable as that of mathematical statements. Higher order experiences are based on numerous individual experiments that can be investigated and tested by anyone. It will not be difficult to discern whether the parts can be expressed through a general principle, since there is nothing arbitrary here.

In the other method, however, in which we try to prove a claim using isolated experiments as if they were arguments, our judgments are often gained surreptitiously and may stand altogether in doubt. Once, however, we have brought together a series of experiences of a higher kind, we can apply intellect, imagination and ingenuity as we like. They will do no harm; rather, they will serve us. The first part of an investigation cannot be careful, diligent, strict and even pedantic enough, since the work is undertaken on behalf of the world and posterity. The materials should be ordered and presented in series and should not be arranged according to a hypothesis or used to serve a system. After that everyone is free to combine the material according to his manner and to create a whole that suits our way of thinking. In this way we will make the distinctions that are necessary and we are able to expand the array of experiences much faster and more purely than if we handle later experiments like extra bricks we cast aside and leave unused in face of an already completed structure.

The opinion and example of the best researchers give me hope that I am on the right path. I trust that this declaration will satisfy my friends who ask: what is the purpose of my work in optics? My purpose is to collect all experiences in this field, to conduct myself all the experiments, and to carry them out in their manifold variations. In this way they are easy to replicate and accessible to other people. Then I present the principles of the experiences of a higher order and wait and see if they let themselves be subsumed under even higher principles. Should the power of imagination and ingenuity at times speed ahead impatiently, the method itself will guide it back onto the right track.

Translation by Craig Holdrege. Goethe wrote this essay in 1792, and it was published for the first time, in a slightly altered version, in 1823. Source of translation: "Der Versuch als Vermittler von Objekt und Subjekt," in Goethe's Werke, Hamburger Ausgabe, Bd. 13 *(Munich: Verlag C. H. Beck, 2002, pp. 10-20).*

This lily shows something special. While a "normal" lily has six petals and six stamens, this one has six petals, five stamens, and one stamen that is also partially a petal. It is the curled structure at the center of the flower. Goethe arrived at many insights by paying attention to such unusual formations. (Photo Craig Holdrege)

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