In Context

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The Newsletter of **The Nature Institute**

#31

Dear Friends,

If we were to name a theme for this issue, it might be "Conversation." This relates in particular to the feature article, which is almost three times as long as any article we have published in *In Context.* As an expansion of a talk Craig was invited to give to a special interest group of the New York Academy of Sciences last October, it represents a significant engagement with the larger scientific community. The Academy member who invited Craig wrote back after the event:

> Thanks for one of the most interesting, quietly charming, and fulfilling lectures that I attended in 40 years as a member of NYAS.
>
> You clearly had your audience fully engaged in a new way of seeing the full scientific process, and were able to sustain that for quite a long period so they got the complete story in the right way. It was very enlightening for both me and my colleague.

I (Steve) have read many summations of the Goethean approach to science, but was so impressed with this particular article that I felt we really must present it here in its entirety, and so bring it to a larger audience. You might want to pass the article along to any scientist friends who are open to new (or should I say "older") ways of thinking.

The theme of conversation seems appropriate for our work in more ways than one. With our new building now well inhabited and "worn in," we are expanding our offerings to people near and far in the form of lectures, workshops, and courses. This is conversation on a very personal level. But there is also engagement with other constituencies on other levels. For example, Henrike is collaborating with Prof. Dr. Kornelia Möller, the director of a teacher training institute at the University of Münster, Germany, and John Gouldthorpe of the Creative Compound in Point Reyes Station, California, to investigate methods of science instruction. Together they have just recently spent a few days at the world-famous Exploratorium in San Francisco, observing how the young visitors interact with and (at least one would like to hope) learn from the various exhibits.

On yet another and entirely different front, Steve has entered into conversation with representatives of the intelligent design movement. This movement is now one of the major cultural currents in American society, and many have wondered how our own work relates to it. There has so far been some published back-and-forth— constructive in nature, we would like to think— and we hope to be able to offer a report in a future issue of *In Context*.

Craig Holdrege　　　　Steve Talbott

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The Nature Institute

EDITOR: Stephen L. Talbott
LAYOUT: Mary Giddens

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The Nature Institute
20 May Hill Road
Ghent, New York 12075
Tel.: 518-672-0116
Fax: 518-672-4270
Email: info@natureinstitute.org
Web: http://natureinstitute.org

Of Weeds, Milkweed, and Monarchs

We continue to add material to our "Unintended Effects of Genetic Manipulation" website (nontarget.org). *The following is derived from two of the more recent reports. The references, not supplied here, are available at* http://natureinstitute.org/nontarget/misc/monarch_disappearance.php and http://natureinstitute.org/nontarget/misc/glyphosate_resistance.php

Farmers began spraying glyphosate on their crops back in the 1970s. A broad-spectrum herbicide marketed by Monsanto under the trade name "Roundup", glyphosate was just one of a number of effective herbicides, and for the next two decades no weed resistance to glyphosate was observed. Meanwhile, Monsanto was genetically modifying certain crops—corn, soybeans, canola, and cotton—so that they would not die when sprayed with glyphosate. These Roundup-resistant crops, first commercially planted in 1996, made it possible for farmers to use the herbicide much more intensely. They could spray glyphosate (and thereby control weeds) not only before the crop emerged above ground, but afterward as well.

As a result, the use of glyphosate expanded dramatically. While 15 million pounds of the herbicide were sprayed on corn, cotton and soybeans in 1996, 159 million pounds were sprayed in 2012 — a 10-fold increase (Food & Water Watch, 2013; based on USDA/NASS data). This had consequences.

For example, before herbicide-resistant crops were available, "weed control required a higher level of skill and knowledge" (Mortensen et al. 2012). But then farmers were offered one simple method to control weeds—spraying glyphosate—and they began planting the same crops year after year on the same fields. The monocultures of industrial agriculture became more and more pronounced. This, together with the greatly increased volume of glyphosate usage, helped to create ideal conditions for the development of weed resistance.

And the weeds responded, leading to a vicious circle of increasing herbicide use and increasing resistance. At first, farmers began spraying more glyphosate, but then, as the resistance problem grew more acute, they added additional herbicides to try to kill the resistant weeds. Farmer expenses for herbicides have risen significantly; for example, farmers who used to pay $25 per hectare for herbicides are now paying $160 per hectare (cited in Service 2013; see also Food & Water Watch, 2013).

But this is no long-term solution, since already some glyphosate-resistant weeds have become resistant to multiple herbicides, making them even more difficult to kill (Heap 2014). Moreover, the problems to consider go far beyond the arms race between resistant weeds and ever more powerful herbicide cocktails. There is, you might say, also "collateral damage."

It happens, for example, that milkweed is common in many midwestern areas where glyphosate is used (along with other herbicides) most heavily. One study estimates an 81% decline in milkweeds in Midwestern agricultural fields between 1999 and 2010 (Pleasants and Oberhauser 2012; see also Hartzler, 2010). And that has a bearing on various insects, including the monarch butterfly.

Monarch larvae feed on milkweed leaves. After metamorphosis, and later in the season, the adult butterflies that live in the Midwest and eastern U.S. make their long migration journey to a remarkably small area in the forests of central Mexico, where they overwinter. It is estimated that 92% of the monarchs wintering in Mexico fed on common milkweed when they were larvae, and that over half of that winter population originated in the Midwest (see Pleasants and Oberhauser 2012). Since monarch larvae are milkweed specialists, and they lay nearly four times more eggs on plants in agricultural fields than on plants in other habitats, it would not be surprising if this substantial loss of food plants were to result in a substantial reduction in the number of Monarch butterflies. And this is the case.

While it is difficult to measure the exact size of the overwintering monarch butterfly population in Mexico, surveys make it clear that there has been a drastic decline in population between 1996 and 2013 (Rendon-Salinas and Tavera-Alonso, 2014). No one would attribute all this decline solely to midwestern herbicide spraying, but it seems apparent that the use of genetically modified, herbicide-resistant crops has been a contributing factor (Brower et al. 2011).

A precipitous decline in monarch butterfly populations was certainly not what either the Monsanto researchers or farmers had in mind when they deployed glyphosate on vast swaths of the American heartland. But there is no good reason why such unintended—and predictable—effects should not now be front and center in our minds.

— Noteworthy —

A New Book on the Heart and Circulation

There are many "textbook truths" in biology: the heart is a pump, the brain thinks, the liver is a chemical factory, genes determine traits. These "truths" are a mixture of metaphor, oversimplification, and convenient models that are used to convey a picture of reality to the learner. They help a learner wrap his or her mind around something. But they are at best crutches, and they often distort the rich complexity of the living world. *The Heart and Circulation: An Integrative Model*, by Branko Furst, an associate professor of anesthesiology at Albany Medical College, tackles the "textbook truth" that the heart is to be understood as a pump that drives the blood through the entire peripheral circulation and back again.

Furst has carried out extensive research into the vast literature on the heart and circulation, including embryological development. What becomes clear in the book is that there is, in fact, no clear picture and no general agreement among researchers about how to understand circulation. This is a significant contribution of the book—it shows that when you go into the details and bring together the research that many different groups are doing from a variety of perspectives, you do not get consensus with regard to explanatory frameworks. The phenomena do not allow themselves to be captured in a simple model. There lies the untruthfulness of "textbook truths."

The heart of a mammalian embryo develops four chambers and valves over time. Early on it is a pulsating tube. There have been two reigning perspectives on how this pulsating tubular heart relates to the blood that flows through it. Some have thought that the pulsating walls massage the blood along via peristaltic contractions. Others have thought it functions like a suction pump. Referring to many different studies, Furst shows how neither model sufficiently "saves the phenomena"—that is, neither provides an adequate picture of the relation between blood flow and heart beat in the early embryo. "After decades of intense research into the action of the embryonic heart, the observed phenomena clearly do not correspond with the existing models and call for reevaluation of the nature of the movement of blood and the role of the heart in the overall dynamics of embryonic circulation" (p. 46).

It is this service that Furst provides again and again in reference to many different aspects of the heart and circulation—development, mature activity, experimental studies, and pathology. By showing the shortcomings of different explanatory models, he is also giving us a sense of the wondrous complexity of the human organism. What in any case becomes clear in the book is how intimately intertwined heart function, blood flow, and the metabolic needs of the organism are. The flow of blood in the embryonic heart, for example, plays a significant role in sculpting the mature form and structure of the blood vessels and heart.

Furst suggests that the paradoxes and riddles that show themselves in so many circulation phenomena could be better understood if we expanded our view of heart and blood function. Following a suggestion of Rudolf Steiner, he proposes that the heart, while of central importance in the generation of blood pressure, is not so much a propulsive pump, as (through the action of the valves and heartbeat) an organ that impedes and rhythmically regulates blood flow. Moreover, he shows how intimately connected blood flow in the periphery is with the metabolic activity of the organs and tissues it flows through. The blood is itself an organ, and Furst suggests that if we were to entertain the thought that the blood is capable of autonomous movement, the complex and ever-changing and modulating circulation could be better understood.

He summarizes,

> The heart can be seen as an organ within the vascular loop which not only maintains the perfusion pressure [perfusion is the flow of blood through organs and tissues] but acts as an organ of restraint, setting itself up *against* the flow of autonomously moving blood (p. 91).

This is not a book for the lay person. It is highly technical and written for specialists. I hope it stimulates people working in the field to question some of their fundamental assumptions and to look afresh at the remarkable life that pulses within us. *CH*

Winter Course for Farmers Deepens Experience of Nature's Qualities

A diverse group of 25 farmers, gardeners, farm apprentices, beekeepers, and others seeking to better harmonize their work with the natural world joined us in February for our Winter Intensive Course, "Experiencing the Deeper Nature of Nature." Each day began with perspective-stretching exercises from projective geometry led by Henrike Holdrege. That was followed both before and after lunch with hands-on observations of the variety of dynamic processes of metamorphosis within and between particular plant species, which Craig led. The latter work challenged everyone to apply all their senses to heighten their capacities to perceive plant qualities—including an afternoon of tasting, describing, and comparing several apple varieties from a local biodynamic farm.

The plant studies also included quiet, snowy treks through the nearby preserve stewarded by The Nature Institute. There the group practiced two complementary ways to sharpen and expand their awareness of the complex flow of relationships within these woods and wetland. Each person tried to alternate between what Thoreau called a "sauntering of the eye"—attending to the whole peripheral world of natural phenomena with a broad, very open sense of receptivity—and a much keener focus on some particular natural phenomenon that called out for special attention. Such precise focusing on the qualities of a track scratched in the snow by a field mouse, or the rustle of wind through a pine tree, or the pungent taste of a broken twig of spicebush requires intentional perception of the details revealed by as many senses as possible.

Bruno Follador, an expert on biodynamic composting and soil fertility who is pursuing advanced research and training in Goethean science at the Institute this spring, also treated participants to a lesson on his specialty. This included an introduction to the process of making chromatography images of compost and soil samples and a presentation about how they can be used in qualitative assessment of compost and soil quality.

Each afternoon ended with astronomy lessons with Henrike that focused especially on the movements of the planets in relation to both the Earth and the Sun, inviting everyone to expand their awareness to this even larger realm

Exploring vegetables

Apple tasting — five different varieties, courtesy of Threshold Farm

Contrasting tulip and rose

of relationships. Participants were encouraged to "see" the relative movement of the planets in part by actually physically enacting together those movements as a group. Despite the bitter cold, many participants also joined Henrike for guided nighttime star-gazing in the snow. They were rewarded by Jupiter's brilliant rise. Below are written reflections from a few participants that give a further sense of the week.

"I appreciated the geometry in the morning—a kind of unraveling of mind—and then going into plants that were grounding. But the unraveling of mind helped to bring about a different perspective, or way of thinking—open to looking at [phenomena] differently. And Astronomy felt right to close—bringing all we touched and thought about into something much more expansive." — *Beekeeper*

"Overall amazing experience—really achieved the goal of expanding ways of seeing for me. All three content areas really reinforced each other and came together in unexpected ways. I feel that I have new concrete tools for perception and understanding—both outwardly in nature and inwardly for myself—different ways of walking through the woods, looking at the stars, and conceptualizing the infinite."
— *Food and Farming Consultant*

"You are helping us to understand, remember, and embrace the many ways we can open our senses and our minds to the wonders of our complex and beautiful world—this quality of being open, awake, and curious is crucial to working with the life forces of the farm or garden. We must learn our own connection with the world through the refinement of the senses and the ability to shift our perspective if we are to be good stewards of the infinite other connections that compose the environments that are our livelihood."
— *Biodynamic Farming Apprentice*

"Having studied and worked with Biodynamics for over ten years, I am always refreshed and reinvigorated by your unwavering dedication to phenomena, to direct observation, and to critical thinking. It stands somewhat in contrast to, but mostly as a complement to, other ways of teaching and exploring biodynamics. I feel I can see and do my work in new ways after taking in your teaching and writing. Thank you."
— *Gardener and Landscaper*

At the Institute

Still ahead: **"More Humus – More Humanity: The Inner Nature of Our Agricultural Crisis."** This weekend workshop (May 16-18) with Bruno Follador is concerned with soil, compost and both the inner and outer relation of the human being to soil and farm health. Bruno, who is working and studying at The Nature Institute this spring, is an expert in qualitative assessment of soil and compost and uses chromatography as part of his work to gain greater qualitative understanding. For more on Bruno, see "Compost, Quality, and Human Engagement" on page 8.

Also to come: **"Resurrecting and Transforming the Social World,"** second lecture in a series by Christopher Schaefer, will be held May 20.

• **Colloquium on quantum physics**. On November 18, Johannes Kühl, head of the Science Section at the Goetheanum in Dornach, Switzerland, led a day-long consideration of themes in physics. About a dozen participants shared in Johannes' reflections on particles, radiation, and the puzzles of quantum physics, capped off by vigorous discussion.

• **Astronomy**. Over five evenings in March, April, and May, Henrike Holdrege and eurythmist Jeanne Simon-MacDonald led a group of stargazers in night-sky observations, eurythmy, and classroom study.

• **Evolution**. In April Craig gave three public talks on evolution. The talks developed out of last year's summer course on the topic and a workshop for science teachers he gave in California. The main question he posed: How can we conceive of evolution as a truly developmental process over long periods of time? This requires studying development in the present very carefully. Craig has also been concerning himself with the picture of human evolution provided by hominid fossils. He presented some of this work in the talks.

• **Social Art and Social Science in Everyday Life**. Christopher Schaefer gave a talk in April on the inner development needed to make social interactions more conscious and healthy. He explored how we are all social artists and social scientists engaged in the effort to understand and build up a healthy social world. Schaefer is co-director of the Center for Social Research at the Hawthorne Valley Association and the author of several books.

• Mathematics Alive! In March Henrike Holdrege and Marisha Plotnik led our fourth weekend workshop for middle school math teachers. With a new topic each year, the workshop serves as a professional development opportunity for teachers to deepen their experience of mathematics and to gain new ideas for math teaching. This year the workshop was at maximum capacity with 22 participants, and the work focused on algebra (linear equations) and negative numbers. One main challenge here is for teachers to overcome the tendency for algebra lessons to become a place where rules are learned and applied, rather than math becoming an opportunity for students to actively engage their creative thinking capacities.

One young teacher wrote in her evaluation of the weekend:

> What I learned and will take with me is the importance of forming a relationship with numbers. To allow numbers to root themselves in us internally and that this is a growing relationship for the rest of one's life. I want to deepen my own relationship with numbers and foster that relationship with my students. I loved the games and mental math exercises that we learned and am excited to use them inside and outside of math class. I also want to work with my students to create math endurance so that they take the time to be frustrated and allow themselves to struggle through problems to make progress. I feel stronger, smarter and more confident leaving this workshop knowing that the language and conversation of mathematics is a journey and an enjoyable one. I am grateful to have been here. You both are an inspiration and a light for women in math. I only wish it was a longer workshop because there is still so much to learn. As I become more comfortable and confident in my math skills, I look forward to making my lessons more creative and even spiritual for my students with the use of pictures and stories. Collaboration is a fundamental piece of math. Thank you.

Teachers working on math problems in pairs

Out and About

• Craig in California. Craig spent an intense ten days in California in February. He gave two two-part workshops at the Western Waldorf Educators' Annual Conference at Rudolf Steiner College in Fair Oaks, California. The conference topic was about technology. In one of the workshops Craig guided dialogue on the topic of technology in the middle and high school. The group looked at how the increased use of digital technologies impacts learning and the life of students today and discussed what capacities are enhanced and negatively affected by this shift in culture. The second workshop addressed the ways in which first-hand sensory experience provides a kind of grounding in the world that becomes ever-more important as students increasingly pursue lives that are mainly technology-mediated.

At the Summerfield Waldorf School Craig gave four talks and a three-part workshop in a conference for high school and middle school science teachers. The conference topic was "From Phenomena to Insight." Through Craig's work and the contributions of the other main presenters, Jon McAlice and Wilfried Sommer, the participants spent four days experiencing, learning about and discussing the characteristics of phenomenological science and how it can be taught.

Craig then spent three days with friend and colleague John Gouldthorpe, conversing about the practice and promotion of phenomenology and taking long walks at John's "Creative Compound." The compound is in Point Reyes Station, one of California's most inspirational natural settings. As a final treat of the trip, Craig had lunch with writer Michael Pollan in Berkeley, where Michael is a journalism professor at the University of California. They spent an engaged two hours talking about plant intelligence, materialism, contextual thinking, and more.

• At Camphill Copake: Projective Geometry. In March and April Henrike taught a weekly class on projective geometry for first-year students in a Bachelor's Degree program in social therapy at Camphill Copake, New York. The twelve students come from eleven different countries and work as part of their training as co-workers within the Camphill community for people with special needs. They also have classroom studies. Projective geometry was new to all the students. They engaged actively in the work, creating drawings and wrestling with the challenging idea of the infinite. Halfway through the course a young woman asked: "Why isn't projective geometry taught anymore as part of general college or high school education?" A good question, since this kind of geometry exercises mind and thinking in special ways.

• In **Spring Valley, NY**, Craig gave a half-day workshop at the **Pfeiffer Center**'s course for Biodynamic agriculture in March. His focus was on learning to understand essential qualities of plants and animals. Also in Spring Valley Craig gave a public talk on the theme of his book, *Thinking Like a Plant*.

• At the **Omega Institute** in Rheinbeck, NY, Craig and Bruno Follador participated in a **Food Quality Gathering** in late April. The gathering was the second of its kind and the goal was to bring together farmers, gardeners, consumers, and retailers to speak about food quality: how to assess and improve it, and how to expand public awareness of food quality.

• **In Virginia**. In April Henrike and Craig traveled to Sperryville, Virginia. They gave an all-day public workshop on the theme, "Cultivating Living Thinking: A Way of Knowing as a Way of Healing." Craig also gave an evening talk on "The Plant as a Teacher of Living Thinking" based on his recent book.

• **Observational Studies at San Francisco's Exploratorium.** Henrike traveled to California in early May for a second visit to the Creative Compound in Point Reyes Station. She was accompanied by Prof. Dr. Kornelia Möller, who is the director of a teacher training institute at the University of Münster, Germany, and who specializes in experience-based science learning in elementary school. For three days, together with John Gouldthorpe of the Creative Compound, they visited the Exploratorium in San Francisco to observe children in their interactions with the physics demonstrations and experiments. The focus of their research: In what sense and to what degree are the children learning?

Compost, Quality, and Human Engagement

In February Bruno Follador, who comes from Brazil, joined the work of The Nature Institute for four months. Bruno comes to The Nature Institute on the one hand with a deep commitment to the Goethean approach to science and on the other hand with five years of experience working to improve composting and soil fertility. He has expertise in the qualitative assessment of compost using chromatography. But he is not mainly interested in using this method to test, in an external way, compost and soil quality. Rather, for him it is a practice that helps to discipline his perception when he is working with composting as an integral part of the farm organism.

During his time here Bruno is carrying out a number of interwoven activities. He is pursuing further training in the Goethean approach to science by participating in our courses, workshops, research meetings, and through conversations with staff. He is also deepening his understanding of the Goethean approach through the study of books and articles. He is giving presentations and workshops to farmers, gardeners and interested lay people about composting, its role in the farm organism, and how composting practices can be improved and qualitatively assessed. It is a real pleasure and enrichment for our work to have Bruno with us.

In May Bruno will be conducting a workshop entitled "More Humus – More Humanity: The Inner Nature of Our Agricultural Crisis." See the brief note on page 6. (You will find more detailed descriptions of this and other workshops on our calendar page: 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, 2013, and March 31, 2014: you have our heartfelt thanks!

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Goethe and the Evolution of Science

Craig Holdrege

This article is based on a talk Craig gave in October 2013 at the New York Academy of Sciences. The talk was sponsored by the Lyceum Society within the Academy, a group consisting mainly of semi-retired and retired scientists who invite guest speakers to speak about topics of interest. About 35 scientists attended Craig's talk, which was followed by a lively question and answer session. Clearly, there was a keen interest in learning more about Goethe and the relevance of his approach for modern science.

Already at the age of 25—in 1774—Goethe was famous in German-speaking Europe for his literature. His novel *The Sorrows of Young Werther* was a best seller. During his long life—he died at age 82 in 1832—Goethe's literary productivity never ceased. He is perhaps the most well-known and influential German-language poet and writer of the modern era.

Soon after attaining his youthful fame, Goethe moved in 1775 to the small duchy of Weimar. There he was a companion of the young duke, served as a minister in the duchy, and within a few years took on an almost unbelievable number of duties (Barnes 1999; Richards 2002). He was privy councilor, superintendent of buildings, mines, and forestry; he became president of the duchal chamber and also of the war council. His artistic talents were put to use as court poet and director of the drawing academy, and he wrote, produced, and acted in plays at the court theater.

Through his practical duties he become increasingly interested in science. He learned botany as he guided the management of the duchal forests; he studied geology, which he came to know firsthand in his visits to mines and sites for new mines. As a teacher of anatomical drawing at the drawing academy, he sought out anatomist Justus Christian Loder and attended his anatomical demonstrations at the University of Jena. He also studied anatomy privately with Loder, originally with the aim of improving his artistic rendering of the human form, but increasingly because he became intrigued with human and animal form for their own sake.

Over time Goethe pursued his interests in a variety of areas of science—botany, comparative anatomy of animals, geology, color, and meteorology. Goethe was no dabbler. He delved into each area by studying current literature in the field, reading about its history, interacting with and learning from experts, and by carrying out his own observations and experiments. It's hard to believe how all this was possible in addition to his artistic and administrative endeavors.

In his scientific pursuits Goethe developed a unique way of doing and viewing science. He made discoveries that were important in the history of science, he stirred up the scientific community by challenging significant authorities, and most importantly, in my view, practiced a way of doing science and articulated a view of science that still today stands out in its uniqueness. Here I want to paint—through considering some of his work in comparative anatomy and botany—a picture of Goethe's approach to science and discuss why I think it is still highly relevant and important today. Sometimes when I bring up Goethe's approach to science, people say, "Craig, we need to move beyond Goethe." That has truth to it; but even more true is that in important ways we haven't even reached Goethe. That's why in going back to Goethe we can also move into the future.

Nature

Surprisingly, in the inaugural (November 4, 1869) issue of *Nature*—which was to become the pre-eminent journal of science—Goethean thought had a prominent place. The guest editorial, written by the famous proponent of science and Darwinism, T. H. Huxley, began with a long quotation from a "wonderful rhapsody on 'Nature,' which has been a delight to me from my youth up." Here are some excerpts from that rhapsody (albeit in a different translation from the one Huxley quoted; see Goethe 1995, pp. 3-5):

> Nature! We are surrounded and embraced by her – powerless to leave her and powerless to enter her more deeply.…
>
> She brings forth ever new forms: what is there, never was; what was, never will return. All is new, and yet forever old.

We live within her, and are strangers to her. She speaks perpetually with us, and does not betray her secret. We work on her constantly, and yet have no power over her….

She is the sole artist, creating extreme contrast out of the simplest material, the greatest perfection seemingly without effort, the most definite clarity always veiled with a touch of softness. Each of her works has its own being, each of her phenomena its separate idea, and yet all create a single whole….

There is everlasting life, growth, and movement in her and yet she does not stir from her place. She transforms herself constantly and there is never a moment's pause in her. She has no name for respite, and she has set her curse upon inactivity. She is firm. Her tread is measured, her exceptions rare, her laws immutable.

She thought and she thinks still, not as man, but as nature. She keeps to herself her own all-embracing thoughts which none may discover from her.

All men are in her and she in all….

Life is her most beautiful invention and death her scheme for having much life….

She is wise and still. We may force no explanation from her, wrest no gift from her, if she does not give it freely…

She is whole and yet always unfinished. As she does now she may do forever. To each she appears in a unique form. She hides amid a thousand names and terms, and is always the same….

This hymn to nature was written by a friend of Goethe's, Georg Christoph Tobler, in 1782, and is based on Tobler's conversations with Goethe. When Goethe read the piece late in life, he remarked that it had accurately represented his views. (The hymn has usually been attributed to Goethe himself and was included in his collected works.) It expresses a dramatically dynamic view of a nature in which everything is intertwined. Huxley felt that "no more fitting preface could be put before a Journal, which aims to mirror the progress of that fashioning by Nature of a picture of herself, in the mind of man, which we call the progress of Science…." And while Goethean thought would hardly be greeted so warmly today in the pages of *Nature*, Huxley sensed something deep and timeless in this view of nature and concluded his editorial by remarking, "It may be, that long after the theories of the philosophers whose achievements are recorded in these pages, are obsolete, the vision of the poet will remain as a truthful and efficient symbol of the wonder and mystery of Nature." That same vision informed Goethe's work as a scientist.

A Bone of Contention

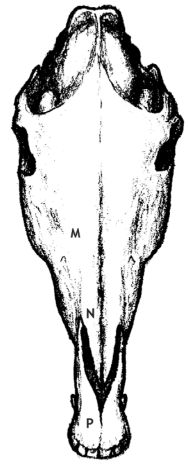
While studying human and comparative anatomy in the 1780s, Goethe learned that leading authorities in the field believed that the human being does not possess a particular bone in the skull. At the time this bone was called the *os intermaxillare,* today we speak of the premaxilla or premaxillary bone. Apes, monkeys and other mammals possess this bone and the prevailing view was that it is "a characteristic that separates ape from man" (Goethe 1995, p. 111).

This view did not sit well with Goethe, and he began an extensive study of human and animal skulls. He came to the conclusion that the human being does in fact possess a premaxilla and wrote in 1786 a scientific paper on the topic (Goethe 1995, pp. 111-116). The premaxilla is especially prominent in animals with a long snout, such as the horse (Figure 1). It forms the front-most part of the upper jaw and houses the upper incisors. Animals with shorter skulls have a proportionally shorter and smaller premaxilla, but it is clearly visible, say, in lions or monkeys (Figure 2). It is not so readily discernible in the human skull, which is so round and displays no forward jutting of the jaw (Figure 3). Goethe—typical for his approach—looked at a variety of adult skulls, but also skulls of children and embryos. Especially in younger skulls the sutures between the upper jaw bone (maxilla) and the premaxilla are clearly visible and they are also visible in some adult skulls. What often occurs is that the premaxilla and upper jaw bone fuse in the course of development. But the premaxilla is present. Goethe is often described as the discoverer of the bone; however, he studied the works of earlier anatomists and found that the bone had been described by some and he named them in his paper on the premaxilla.

Finding the premaxilla in man gave Goethe the greatest pleasure. He wrote to his friend Herder: "I have found—neither gold nor silver, but something that makes me unspeakably glad—the os intermaxillare in man! While comparing human and animals skulls with Loder, I came on its tracks and saw it there" (cited in Richards 2002, p. 369). Why was Goethe so excited by the discovery of this inauspicious bone?

This becomes clear in a letter that Goethe wrote to his friend Knebel in 1884:

> Moreover, man is very closely related to the animals. Unity of the whole makes every creature into that which it is. Man is man as well through the form and nature of his upper jaw as he is man through the form and nature of the tip of his little toe. And thus is every creature only one tone, one hue of a great harmony, which one must



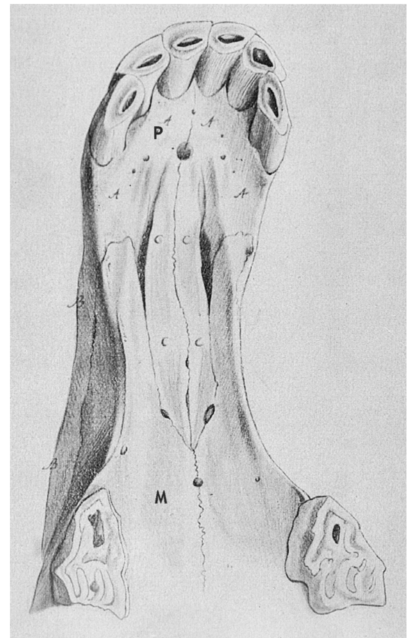
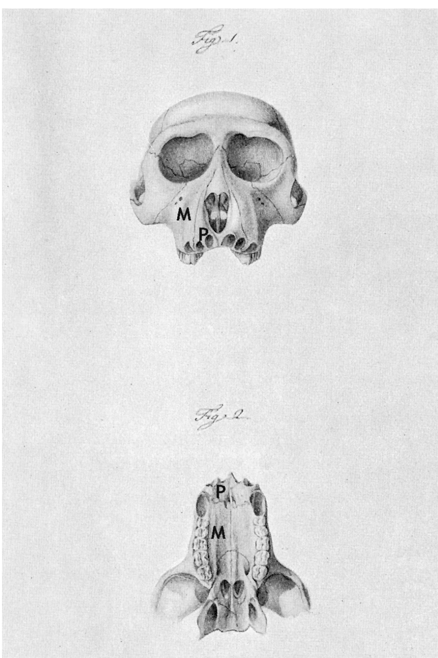
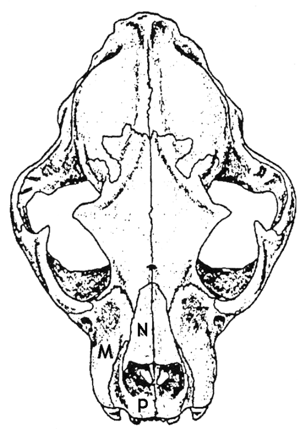


Figure 1. The skull of a horse, showing the premaxillary (P), maxillary (M), and nasal (N) bones. The palate view of the upper jaw at the right is from Goethe's original publication on the premaxillary bone (labeling added by CH).





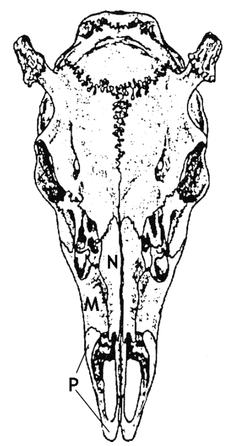
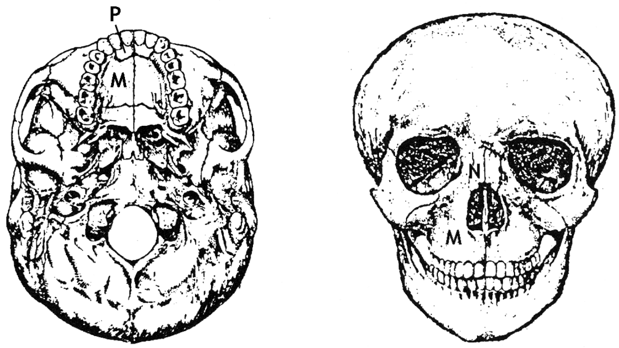


Figure 2. The skulls of a monkey (left), mountain lion (middle) and white-tailed deer (right) showing the premaxillary (P), maxillary (M), and nasal (N) bones. The drawing of the monkey skull is from Goethe's original publication on the premaxillary bone (no species or genus was indicated; labeling added by CH).

> thus study in the whole and at large, lest every particular become a dead letter. I have written this small treatise from that point of view, and that is really the interest that lies hidden therein. (Cited in Richards 2002, p. 375)

In his studies of living nature Goethe considered how every part of a larger whole is truly a member of that whole and expressive of it. All the bones in the human frame are related to our upright posture. It's not a particular bone that makes us human but how the individual bones are configured within the context of the whole organism. Goethe had a remarkable sensitivity to this essential feature of organic life. Therefore, when he encountered a view that made presence or absence of a single part into an essential distinguishing characteristic he felt something was awry. His response was to go into great detail in observation, look at manifold species and specimens, take variation seriously, and then describe the facts and relations. Again and again the facts bore out that there is unity in nature and that the distinctiveness of different organisms is not a matter of having this or



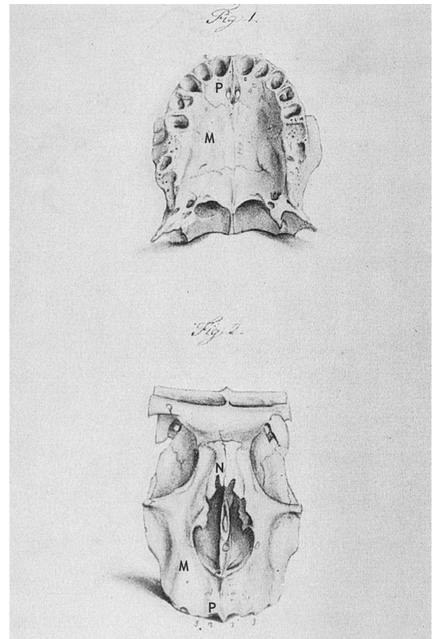


Figure 3. Adult human skulls, showing the premaxillary (P), maxillary (M), and nasal (N) bones. The drawings on the right show two different detail views of the same skull and are from Goethe's original publication on the premaxillary bone (labeling added by CH); note that on the skull from Goethe's publication, the premaxillary bone is visible both in the view from the outside front of the skull (bottom drawing) and also when looking at the hard palate. In contrast, in the skull at the left, on the outside front of the skull, the sutures of premaxilla and maxilla have fused to create one bone, while the sutures are still visible in the hard palate (top drawing).

that part or organ, but rather of how the parts are integrated within the whole. As he wrote in *Faust*, "consider the what, but consider even more the how" (*Faust* II, line 6992).

You may think it quaint that people could believe that a single bone could distinguish humans and animals. But if you fast forward to the end of the twentieth century and substitute "gene" for "bone" then you will find that the tendency to hold distinct parts or entities to be essential distinguishing factors is still happily alive. In 1998 an article appeared in *Science* that had the subtitle, "Which of our genes make us human?" (Gibbons, 1998). The article reports that there is hardly any difference between the DNA from humans and chimpanzees. Approximately 98.5% of the DNA is the same and the author draws the following conclusion:

> This means that a very small portion of human DNA is responsible for the traits that make us human, and that a handful of genes somehow confer everything from an upright gait to the ability to recite poetry and compose music.

Had Goethe been alive in 1998, I'm sure that he would have rebelled against this view. And had he studied the details of genetic research the way he studied comparative anatomy, he would have seen his view of organic life born out even at the level of molecular processes. This is something we have been studying at The Nature Institute for many years—all modern research points to the fact that an organism dynamically orchestrates its genome and not the other way around. (See natureinstitute.org/gene/index.htm and BiologyWorthyofLife.org.)

Wholeness and Isolation

> "With any given phenomenon in nature—and especially if it is significant or striking—we should not stop and dwell on it, cling to it, and view it as existing in isolation. Instead we should look about in the whole of nature to find where there is something similar, something related. For only when related elements are drawn together will a whole gradually emerge that speaks for itself and requires no further explanation." (Goethe 1995, p. 203 [*Theory of Color,* Part Two, paragraph 228; this transl. CH])

Goethe's approach to science was truly ecological—he always tried to understand things in relation to their broader connections. He was keenly aware of the errors that occur when we focus too exclusively on isolated details—whether in observation of natural phenomena or in carrying out experiments. In his seminal little essay "The Experiment as Mediator of Subject and Object," written in 1792, Goethe discusses scientific methodology. Because he had learned that "in living nature nothing happens that is not in connection with a whole," he believed that a scientist must take utmost care when looking at individual facts or performing individual experiments (Goethe 2010;

following quotations are from the same essay). First, the observations and experiments should be carried out multiple times to verify them—a widely recognized practice today. Next, since each experiment or experience represents, an "isolated piece of knowledge," the question becomes: "how do we find the connections between phenomena or within a given situation?" In experiments, "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." Similarly, a characteristic of an organism, whether a bone (as we saw in the premaxilla) or a gene, needs to be viewed at the very least in its variations (morphologically and physiologically), in its context within the organism as a whole (which also changes over time and in different circumstances), and in relation to the "same" characteristic in different organisms.

This approach leads you as a scientist to be cautious and also skeptical about scientific proofs or discoveries provided by single experiments. Those proofs and discoveries are telling you about, say, a gene within a particular experimental or clinical context, not about the "ecological" gene of organismic reality. As Goethe writes, "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." If we take seriously these limitations, we realize that "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's not hard to see that Goethe worked in a careful and self-critical way. His approach was taken up in an especially rigorous and consequential way by twentieth-century neurologist Kurt Goldstein (1878-1965). Goldstein led a clinic after World War I in Frankfurt, Germany, that treated many brain-damaged soldiers. He was forced to leave Germany, as a Jew, already in 1933, and he wrote his brilliant book, *The Organism: A Holistic Approach to Biology,* in exile in Amsterdam. He then settled in the United States.

Goldstein realized the shortcomings of contemporary views of the nervous system and human biology and behavior. For example, scientists and doctors were then keen—as they are today—on localizing specific functions in specific parts of the nervous system. But Goldstein followed Goethe's approach of studying variations of function and structure under different conditions and circumstances. He realized that even simple reflexes are not "automatic mechanisms" but variably depend on the momentary state of the person and the particular task at hand. The patellar reflex as the doctor elicits it during a physical exam is not simply the same reflex (the same "mechanism") that comes into play when I climb stairs, since it is modified by and acts in the service of the whole organism at that moment (see Holdrege 1999). As Goldstein writes:

> If the organism is a whole and each section of it functions normally within that whole, then in the analytic experiment, which isolates the sections as it studies them, the properties and functions of any part must be modified by their isolation from the whole of the organism. Thus they cannot reveal the function of these parts in normal life. There are innumerable facts which demonstrate how the functioning of a field is changed by its isolation. If we want to use the results of such experiments for understanding the activity of the organism in normal life (that is, as a whole), we must know in what way the condition of isolation modifies the functioning, and we must take these modifications into account. We have every reason to occupy ourselves very carefully with this condition of isolation. (Goldstein 1971, p. 10)

This realization poses a real challenge for science and for knowing in general:

> As soon as we attempt to grasp [living organisms] scientifically, we must take them apart, and this taking apart nets us a multitude of isolated facts which offer no direct clue to that which we experience directly in the living organism. Yet we have no way of making the nature and behavior of an organism scientifically intelligible other than by its construction out of facts obtained in this way. We thus face the basic problem of all biology, possibly of all knowledge. The question can be formulated quite simply: What do the phenomena, arising from the isolating procedure, teach us about the "essence" (the intrinsic nature) of an organism? How, from such phenomena, do we come to an understanding of the behavior of the individual organism? (Goldstein 1995, p. 27)

The analytical process—or practical reductionism as I call it—through which we go into and focus on details (make them into isolated objects) is a necessary foundation for clear understanding. Otherwise we move in vagaries. But by reducing we lose connections and this is the problem that Goldstein so clearly sees. How do we overcome the limitations of the process of isolation? That is the hard question that Goldstein poses for science, a question I want to begin to address here and then more fully in the following section of the article.

Pursuing a Goethean approach, we never tire of carefully investigating details and, where appropriate, performing experiments. But in this work we give due attention to the process of isolation and its limitations, so that we become aware of how we are interacting with the phenomena. We realize that science is a form of participation in the phenomena and that the way the phenomena appear is also a function of the way we look at them. This does not mean that what we find is "subjective," but that a perspective or point of view belongs to the way something appears. Therefore we need to be just as aware of our point of view as we are of its object. We take first steps in overcoming this one-sidedness by considering the phenomena in question from a variety of perspectives—as Goethe did with the premaxilla and Goldstein with reflexes.

It is not enough, however, to observe a bone in many different species of skulls or in different stages of development in one species. If we only do this then we have a collection of many isolated facts. We need to consciously shift our attention from facts to relations and connections. This means that when we have looked at the premaxilla in, say, a deer skull and have studied its characteristics, we attend to how it fits within that skull and perhaps how the relations change during development.

When we then compare the deer skull to the mountain lion skull we see a different configuration of relations. We see how the premaxilla is part of the tendency toward overall lengthening of the snout and in particular to the lengthening of the forward (distal) part of the snout. The compact skull of the mountain lion has a much smaller and broader premaxilla. When we now shift attention to the limb skeleton we see that the deer has proportionately long legs and it is again the distal parts of the limb (comparable to our feet and hands) that are especially long. In contrast, the lion has short, stout legs and the feet are much shorter. We can then begin to study how these characteristics both reflect and make possible the way the animal feeds, moves, and behaves.

Without going into further exploration of the connections here, I hope you can see how, by moving from one set of facts to the next and by attending to the changing relations, we begin to form a dynamic understanding of parts within the whole. We come to see how the premaxilla is not "just" a bone, but through its configuration shows us something of the nature of a deer, or a lion. The part shows itself in relation to its context within the organism as a whole—we are starting to see it as a true member of the organism. We are on the way to overcoming the limitations of the isolating procedure. We have not abandoned the details but have begun to see them in their significance for the organism.

Goldstein describes the Goethean way to understand the organism in the following way:

> We do not construct the architecture of the organism by a mere addition of brick to brick; rather we try to discover the actual *Gestalt* or the intrinsic structure of this building, a *Gestalt* from which the phenomena, which were formerly equivocal, would now become intelligible…. We can arrive at [understanding] only by using a special procedure of cognition—a form of creative activity by which we build a picture of the organism on the basis of the facts gained through the analytic method, in a form of ideation similar to the procedure of the artist. Biological knowledge is continued creative activity, by which the idea of the organism comes increasingly within the reach of our experience. It is the sort of ideation, however, which springs ever and ever again from empirical facts, and never fails to be grounded in and substantiated by them. Goethe, to whom we owe much for important discoveries in the field of biology, has called this procedure of acquiring knowledge *Schau* [beholding], and the "picture" by which the individual phenomenon becomes understandable (as a modification), the *Urbild* (the prototype)." (Combination of text from two nearly identical paragraphs in Goldstein 1995, pp. 306-7, and 1971, pp. 23-4)

As Goldstein points out, holistic or organismic understanding of life—which simply means good, contextually sensitive understanding—is a qualitatively different kind of knowing than what we practice in reducing and focusing. And while there is a real challenge to understand, not to mention to practice, a Goethean holistic way of knowing, it is, I believe, a further development of a capacity we use in everyday life and in science. What I mean is our ability to recognize relations and patterns.

If our minds were restricted to analysis and the attention to its products, we would never recognize relations and patterns. Any of us can recognize that the premaxilla is present both in a deer and in a mountain lion. Although all particular details are different, there are relational qualities that we recognize, and we can see the similarity despite the differences. All comparison relies on this ability; without it we would be stuck in details. Recognition, however, is not an analytical process. As philosopher Ron Brady points out, "if recognition could be facilitated by analytic means, we would not need to see a picture of an individual in order to make an identification, but a list of characteristics would do" (Brady 2002). Brady quotes biologist C. F. A. Pantin, who describes collecting biological specimens in the field: "if, when we are collecting *Rhynchodemus bilineatus* together, I say, 'Bring me all the worms that sneer at you,' the probability of your collecting the right species becomes high." That is pattern recognition! And someone who has attended to a specific area of phenomena will have much more refined recognition skills than a beginner.

Every scientist makes use of such skills, but they are taken for granted. They form the unreflective background on the basis of which we analyze, and we wake up, so to speak, only in meeting the details—the products of the analysis. But Goethe remained particularly awake to the relations between facts, and he developed this capacity further through his methodical scientific work.

In conventional science the connection between the facts—the analytical details—is provided by generalizations (explanations, theories, laws). They are what integrate the disconnected facts. It's important to see that generalizations are not the same as what we perceive concretely as holistic patterns and relations. Generalizations are abstractions that are concerned with the least common denominator ("the premaxilla is either of two bones located in front of and between the maxillary bones in the upper jaw of vertebrates"). This is correct for all vertebrates, but it tells you nothing about its qualities and significance within any specific organism, which is what we try to discover in following Goethe's approach. Similarly, the law of gravity tells us that both a rock and a feather will fall to the ground, and in a vacuum tube (process of isolation!) we can even observe how they will do so at the same velocity (and "confirm" the law). But while fundamental, this tells us little about the way a feather, loosed from a flying hawk, drifts slowly in the wind and finally comes gently to rest on the ground, or how that feather in its development, structure, and placement contributes to the hawk's remarkable ability to soar upward in thermal updraft (see Talbott 2004).

Goethe's botanical studies will take us a step further in understanding why he thought that adequate knowledge could only be attained by a way of knowing that perceives and beholds—and doesn't only articulate generalizations about—dynamic wholeness in life.

The Dynamic Plant

> "If we look at all these *Gestalten,* especially the organic ones, we will discover that nothing in them is permanent, nothing at rest or defined—everything is in a flux of continual motion. This is why German frequently and fittingly makes use of the word *Bildung* [formation] to describe the end product and what is in process of production as well.... When something has acquired a form it metamorphoses immediately into a new one." (Goethe 1995, pp. 63-4)

Goethe's botanical research was initially guided by his study of Linnaeus' *Philosophia Botanica,* a foundational work on plant systematics and botanical terminology. He learned much from Linnaeus' overview of plant classification and the detailed descriptions of plant parts. Looking back at his botanical research near the end of his life, Goethe wrote (in 1831):

> I gradually became aware that some things on the path which he had marked out and I had taken, were holding me back, if not actually leading me astray.... When I attempted an accurate application of terminology, I found the variability of organs the chief difficulty. I lost the courage to

Figure 4. On the left, a pressed flowering specimen of wild radish (*Raphanus raphanistrum*) showing the different forms of the leaves on the main stem. On the right, all the leaves from the main stem of a different wild radish specimen. The first leaves develop at the bottom of the plant (at the left in the horizontal row); the last small leaf (at the right end of the row) is the uppermost leaf and the last one on the main stem to develop; it precedes the first flower.

> drive in a stake, or to draw a boundary line, when on the selfsame plant I discovered first round, then notched, and finally almost pinnate leaves, which later contracted, were simplified, turned into scales, and at last disappeared entirely. The problem of designating the genera with certainty, and of arranging the species under them, seemed insoluble to me. Of course, I read the method prescribed, but how could I hope to find a suitable classification when even in Linnaeus' time genera had been shattered and separated, and classes themselves dissolved? (Goethe 1989, pp. 159-60)

What impressed Goethe was variety and variability in plants. He looked at them in detail and did not gloss over differences. But the differences were not of the kind that would allow hard and fast boundaries between plant parts or even species and genera. He came to see plants as dynamic and transforming organisms. I'll give a few examples here.

When he looked at the leaves of herbaceous plants—especially annuals—he noticed that the form of the leaves often changes dramatically as one leaf after another develops on the stem (see Figures 4 and 5). The first two leaves—the cotyledons—are already formed in the seeds and are markedly different from the following foliage leaves. The first foliage leaves are usually roundish or oval in shape, the next leaves are larger and the leaf becomes more differentiated—each species in its own way. Then the leaves get smaller and linear, and finally "disappear entirely." It's impossible to say what *the* foliage leaf looks like in any of the plants shown. Rather, there is a sequence of forms that shows how the plant, in developing its leaves, is going through a process of transformation. "Leaf" is not something static and clearly circumscribed, but a dynamic process in the life of the plant.

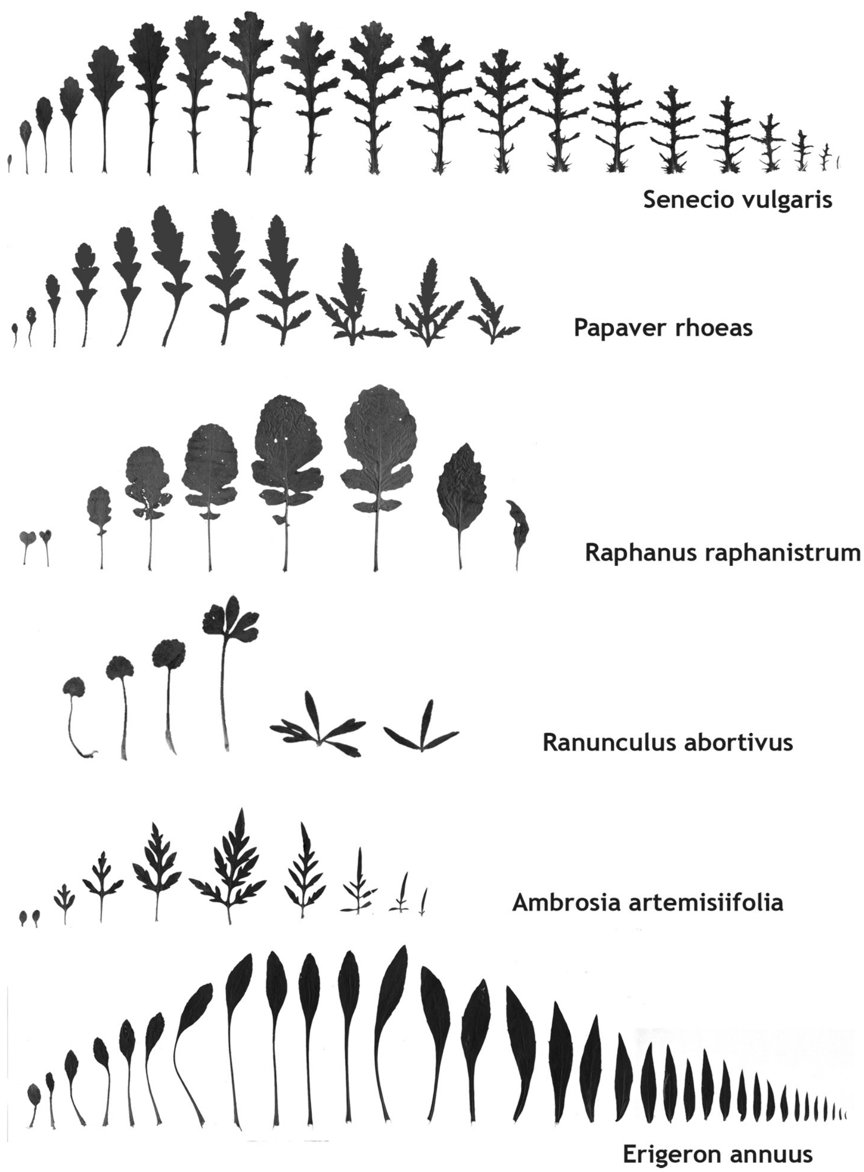


Figure 5. The foliage leaves of different wildflowers.

Figure 6. Two atypical tulips. The upper leaf on the stem at the left has the texture and color of a petal. In the specimen on the right the upper leaf and a petal are not wholly separated and this chimeric form has characteristics of both petal and foliage leaf. (Paintings commissioned by Goethe for *Metamorphosis of Plants.*)

Figure 7. A species of primrose. The flowers of the specimen on the left have the typical tube-like, green calyx that holds the red and yellow petals of the corolla. The atypical specimen on the right has a double layer of petals; the calyx transformed into a corolla. (Paintings commissioned by Goethe for *Metamorphosis of Plants.*)

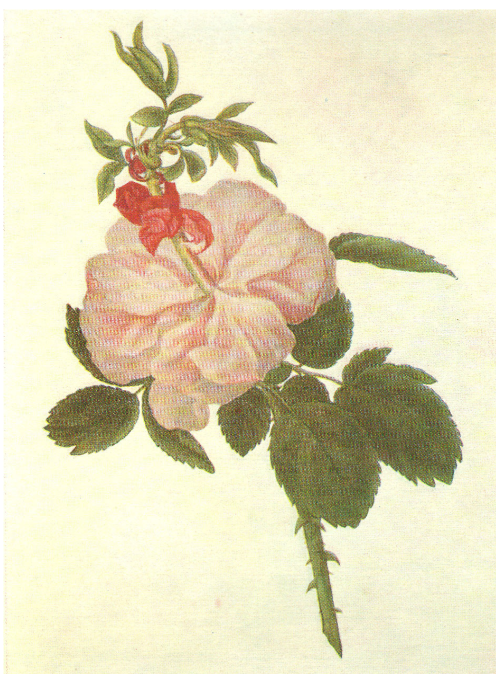


Figure 8. A proliferous rose. Instead of forming stamens and pistils, this rose develops a new stem carrying petal-like and foliage-leaf-like structures. (Paintings commissioned by Goethe for *Metamorphosis of Plants.*)

Figure 9. Top row: normal petals of a rose. Bottom row: atypical petals that have developed partly as stamens. (Paintings commissioned by Goethe for *Metamorphosis of Plants.*)

The process of transformation along the stem continues in formation of the flower, which after pollination progresses further in the development of the fruit and seeds. In his studies, Goethe came to a dynamic view of this process. He writes in his treatise of 1790 on *The Metamorphosis of Plants:*

> Whether the plant grows vegetatively, or flowers and bears fruit, the same organs fulfill nature's laws throughout, although with different functions and often under different guises. The organ which expanded on the stem as a leaf, assuming a variety of forms, is the same organ which now contracts in the calyx, expands again in the petal, contracts in the reproductive parts, only to expand finally as the fruit. (para. 115; in Goethe 1995, p. 96)

One of the ways in which he came to this idea of the unity of plant parts was through his observation of what we would typically call abnormalities. For the publication of *The Metamorphosis of Plants* he commissioned an artist to draw some of these abnormal, but for Goethe important, forms. Figure 6 shows two tulips in which the uppermost foliage leaf has become like a petal of the flower both in color and consistency. Figure 7 shows two different specimens of a primrose variety. The "normal" plant is shown on the left and it has small green sepals that are distinct from the larger red petals. On the right is a specimen in which petals have developed where sepals normally grow; as a result this plant has a double layer of petals. In Figure 8 we can see that a new stem with leaves and petals has developed out of the middle of a flower. And, finally, Figure 9 shows individual parts of the flower that have characteristics of both petal and stamen.

These examples indicate how attentive Goethe was to details that most of us would overlook. But why did he find such abnormalities important? Because when plants can develop petals where foliage leaves, petals where sepals, and stamens where petals normally develop, they are clearly not fixed and determined in their parts. Of course, the developed parts of any given specimen are distinct in their appearance. But when you see the parts in their relations and variations, you become cognizant of the unity of transforming life in the plant. Your attention shifts from the products to the productive source of life, and this is not fixed, but rather flexible and dynamic.

Goethe discovered this dynamic unity of plant during a two-year stay in Italy (which was a prolonged "sabbatical" that Goethe embarked upon in 1786 to escape from what had become the overburdening weight of his duties in the Duchy of Weimar, to which he returned, with fewer responsibilities, after his journey). He writes: "I traced the variations of all the forms as I came upon them. In Sicily, the final goal of my [Italian] journey, the conception of the original identity of all plant parts had become completely clear to me; and everywhere I attempted to pursue this identity and to catch sight of it again" (1989, p. 162). He realized that "in the organ of the plant that we are accustomed to call the *leaf* lies the true Proteus who can hide or reveal himself in all vegetal forms. Forwards and backwards, the plant is nothing but leaf…" (Goethe 2002, p. 622; transl. CH). He also spoke of this true Proteus of plant life as the *Urpflanze* (archetypal plant).

Nothing is easier than to misunderstand what Goethe is talking about with his discovery of the archetypal plant. He did not mean a general scheme; he did not mean something metaphysical; he did not mean some physical genetic potency in germ of the plant. He meant something that becomes visible to the mind's eye as it actively studies the phenomena of plant life. This is a thinking that is perceiving and a perceiving that is thinking, as Goethe put it, that reveals both specificity and universality. Philosopher Ernst Cassirer suggests that Goethe's special contribution to science has been misunderstood because he was practicing a way of knowing that is unique:

> There prevails in his writings a relationship of the "particular" to the "universal" such as can hardly be found elsewhere in the history of philosophy or of natural science. It was his firm conviction that the particular and the universal are not only intimately connected but that they interpenetrate one another. The "factual" and the "theoretical" were not opposite poles to him, but only two expressions and factors of a unified and irreducible relation. This is one of the basic maxims in his view of nature. (Cassirer 1950/1978, p. 145)

In other words, Goethe overcame a dualistic view of the world, but he did so without reducing mind to matter or matter to mind. In a rigorous manner he could speak about "the sensible form of a supersensible plant archetype" (1989, p. 162; transl. modified by CH). This kind of experience relies on the intensification and further development of the everyday capacity we use in pattern recognition. So it is not as though it is something far off and unattainable. It is special, because what our culture has emphasized and trains is the ability to analyze and focus on details of the sensory world and the extended-sensory world mediated by instruments, on the one hand, and on the ability to form generalizations that create a web of meaning for the facts, on the other. This has led to the duality of matter and mind and to all the fruitless attempts to make the world whole again by denying one of the two poles. Because Goethe's approach stays at all times within experience—but experience that encompasses thought and sense—the division that plagues modernity does not arise.

Birthing Ecological and Evolutionary Thought

As we have seen, adequate understanding in Goethe's view can only be gained when we consider the relations and connections in which any given thing is embedded. This is ecology understood as a way of knowing. It is not a matter of content, because it applies to the way we study any phenomena, whether they be rocks, cells, or whole organisms. It leads to an ecological view of the world in which everything is interconnected. So Goethe the ecologist writes in the early 1790s:

> We will see the entire plant world, for example, as a vast sea which is as necessary to the existence of individual insects as the oceans and river are to the existence of individual fish, and we will observe that an enormous number of living creatures are born and nourished in this ocean of plants. Ultimately we will see the whole world of animals as a great element in which one species is created or at least sustained, by and through another. We will no longer think of connections and relationships in terms of purpose and intention; we will progress in knowledge alone through seeing how formative nature expresses itself from all sides and in all directions. (Goethe 1995, pp. 55-56)

This ecological view of nature carries at the same time the seeds of a picture of life evolving on earth. And it is clear that Goethe—with his conception of individual organisms as dynamic, developing beings and his notion that the life of all organisms is interconnected and woven together with the environment—could hardly help but think that life on earth has evolved:

> My laborious and painstaking research was made easier, even sweetened, when Herder undertook to set down his ideas on the history of mankind. Our daily conversation was concerned with the primal origins of the water-earth and the living creatures which have developed on it from time immemorial. Again and again we discussed the primal origin and its ceaseless development, and our scientific knowledge was refined and enriched daily through mutual communication and argument. (Goethe 1995, p. 69; this translation by CH)

These conversations took place in the 1780s. Goethe and Herder were two of a number of thinkers in Europe at the end of the 18th century who were giving birth to the idea of organic evolution. This idea took hold in broader culture only much later, after the publication of Charles Darwin's *Origin of Species* in 1859. While Ernst Haeckel—the champion of Darwinism in the German-speaking world—referred to Goethe as a forerunner of Darwin, this is true only to a degree. Like Goethe, Darwin was attentive to the immense variation in nature and came to view nature dynamically. But in working out his theory, he focused on natural selection—how the environment determines the evolution of organisms, whereas Goethe believed that any development would result from the "inner core" of the organism—what we've discussed in the plant as the living Proteus—forming itself differently in the interaction with changing conditions.

Anthropologist and historian of science Loren Eiseley wrote that "Darwin's primary interest [was] the modification of living forms under the selective influence of the environment. … Magnificent as his grasp of this aspect of biology is, it is counterbalanced by a curious lack of interest in the nature of the organism itself." He goes on to articulate this lack more precisely and in so doing characterizes exactly what stands out in Goethe's approach, namely, the "deep recognition of the life of the organism as a functioning whole which must be coordinated interiorly before it can function exteriorly" (Eiseley 1961, pp. 341-342).

The Metamorphosis of the Scientist

You could say that it was Goethe's gift to sense that he was encountering something of immeasurable depth and potency in every meeting with the natural world. To come closer to that depth and potency without destroying it was his aim: "An organic being is externally so many-sided and internally so manifold and inexhaustible that we cannot choose enough points of view to behold it, and we cannot develop enough organs in ourselves in order to examine it without killing it" (in Steiger 1977, p. 12). The way we develop this inner flexibility and sensitivity of mind so that it becomes an organ that perceives is by consciously encountering the world in its manifold aspects: "Every new object, clearly seen, opens up a new organ of perception in us" (Goethe 1995, p. 39; this translation by CH).

It is up to us to adapt ourselves to what the phenomena have to show—and not primarily to adapt them to our habitual ways of knowing. Progress in science, in Goethe's sense, entails changing ourselves, for "if we want to behold nature in a living way, we must follow her example and become as mobile and malleable as nature herself" (Goethe 1995, p. 64; this translation by CH).

Toward the end of his life Goethe spoke of a "delicate empiricism that makes itself utterly identical with its object, thereby becoming true theory" (Goethe 1995, p. 307). Here the meaning of theory has shifted from an abstract, universal generalization to a concrete and intensive perception of the relations among phenomena. Goethe used the word theory in a way similar to the meaning it had for the ancient Greeks. *Theoria* meant to view a spectacle or a performance; it had to do with direct participation and perception in a happening in the world (Gadamer 1981 and 1998). But Goethe's theory—insight into the "performance" of the world—is gained only after we go through the eye of the needle of analysis. As Goldstein says, it is insight that "springs ever and ever again from empirical facts, and never fails to be grounded in and substantiated by them" (1971, p. 24) .

Goethe knew that he was extending the boundaries of science, but felt this is necessary if human knowledge is to become a truer expression of the life of nature. And when he wrote that "this enhancement of our mental powers belongs to a highly evolved age," he knew that the necessary metamorphosis of the scientist would be a long-term project (Goethe 1995, p. 307).

Today and for the Future

In closing I'd like to summarize a few of the ways in which I think Goethe's work in science is important today and for the future.

Good Science

"Goethe's understanding of scientific procedure marked him not simply a good scientist for the time, but a good scientist for all time" (Richards 2002, p. 408). Historian and philosopher of science Robert Richards comes to this conclusion based on extensive research into Goethe's scientific writings. Because Goethe realized that science is a form of interaction and participation in things, he was especially careful, methodical, and critical. He did not hold the naive view—still widespread today—that science presents the one objective revelation of "the way things are." He saw the confusion and misunderstanding that arises when we don't take the human knower and doer into account as part of the scientific process and product.

In this respect he was far ahead of his time and realized long before the advent of quantum physics that observer and observed are inextricably interwoven. For him this implied that we must refine ourselves as instruments of knowing in the careful and extensive interaction with concrete phenomena:

> Among the objects we will find many different forms of existence and modes of change, a variety of relationships livingly interwoven; in ourselves, on the other hand, a potential for infinite growth through constant adaptation of our sensibilities and judgment to new ways of acquiring knowledge and responding with action." Goethe 1995, p. 61 (written 1807; published 1817).

Goethe saw that progress in science depends upon the development of inner capacities and sensibilities—and not only on the ever further refinement of external instruments and methods and ever grander generalizations. You could say that it's an effort to create a science that is itself more whole by integrating it into the whole—and that means the developing—human being.

Understanding Life

Goethe was keenly interested to the life and vitality of nature. In his studies he developed a growing understanding of the dynamic and holistic nature of organisms. With a sense of the organism as a dynamic whole and with a Goethean methodological awareness, you can gain a foundation to think about topics such as genetics and evolution in fresh ways. Twentieth-century biology was dominated by the gene-centered explanation of inheritance. When scientists make discrete elements that result from the process of isolation ("genes") foundational to all life processes, you can know that something gets lost. And that something is the dynamic life of the organism. In all genetic "explanations" the organism as an active agent is presupposed but not studied as such. Genetics (and evolutionary biology) suffer from inadequate knowledge of the dynamic whole organism.

With the plethora of new discoveries in molecular biology, scientists can hardly fail to confront the inadequacies of the standard explanatory frameworks. As a leading scientist recently remarked, "we can now see the Modern Synthesis as far too restrictive and that it dominated biological science for far too long. … The organism should have never been relegated to the role of mere carrier of its genes" (Noble 2013). Scientists are amassing huge amounts of data and information about dynamic interactions at the molecular and cellular levels. The overriding habit of mind, however, is to treat individual substances (molecules) as foundational and then to build up a picture of the whole by imagining millions of separate mechanisms networking to make an organism. But this view makes separateness fundamental, which is the problem: separateness is precisely the condition we impose on things by investigating through the process of isolation; the attempt to understand the organism in this way is futile and leads to a skewed view of the organism and its life.

What we need are a few hundred years in which biologists take the character of the organism in its interconnectedness, dynamics, and agency as primary and work to integrate products of analysis into a coherent picture of the organism and its interactions at all levels of its life. This understanding, even in its beginnings, can, I believe, also contribute to a richer and more nuanced picture of evolution. Goethe's approach can provide much needed orientation for this essential undertaking.

Science Education

From a Goethean perspective, the evolution of science depends on the metamorphosis of the human being. If science education is to support this evolution, it will need to shift its emphasis from a focus on learning facts and theories to developing capacities. You can often hear people say something like: in graduate school I learned what science is really all about. Why? Because in graduate school you do research, you struggle and notice how messy and rewarding scientific inquiry can be. You engage in a real process. Before that—especially in biology—you may have learned thousands of facts via PowerPoint presentations and learned to interpret them within accepted frameworks. You learned from a textbook and maybe didn't realize that the facts of the topic are embedded in a worldview, since that never was explicitly discussed or questioned in your classes. In lab classes you encountered phenomena, and if you were lucky you may have had field courses in which you got to observe and learn about living organisms in their actual environments. One unsettling symptom of biology education today is that you can get a B.S. in biology without having once observed a living creature in its natural environment! Thankfully, there is also a growing movement toward inquiry-based learning in science.

When we shift the focus to capacity-building and science-as-process, learning science is, from the outset, about exploration and meeting the world (see also Holdrege 2013, chapter 6). The exact nature of that exploration will depend on the age of the learner. But real exploration is essential to any learning process—whether we are in kindergarten, graduate school, or in a professional development program. Science education is about getting students involved and letting them come into contact with the wonders of the natural world (which can be found in a weed in the schoolyard as well as in a national park). It's about seeing things in relation to each other and exploring connections. It's about letting students experience how understanding of nature can emerge, say, through a series of experiments. As critical thinking capacities grow, it becomes important to confront the ideas that have already been thought in science. Imagine high school and college students learning science as a human and often disorderly but wonderful endeavor and grappling with theories as provisory ways of understanding that can both help and hinder further exploration. Real learning involves letting students find, formulate, and follow questions they develop in their encounters. It's about making mistakes and learning from those mistakes. It's about an adventure.

It's not hard to see that this way of working can engender interest, flexibility of mind, and the will to creative exploration. Moreover, because it's all about people engaging in a process of interaction with things and learning through the experiences, it helps human beings become more firmly rooted in the world and at the same time cultivates open-mindedness. What more could we want?

The Evolution of Understanding

In a radical way Goethe expanded the notion of scientific understanding, which becomes especially clear in his biological work. This seems to me to be where he presents the most significant challenge to science. Goethe articulated biological understanding as the direct beholding (*Anschauung*) of what constitutes the living wholeness of the organism. It's a form of knowing that allowed—or compelled—him to speak of a "Proteus" or "archetype" that informs the life of the organism. Volumes have been written about this central feature of Goethe's science—volumes of deep misunderstanding and of deep understanding and clarification. (For a recent lucid contribution, see Riegner 2013.) What's been done much less is to *practice* this way of knowing, since only through practice do its real challenges and its real promise become experience. Through practice the seed that Goethe sowed can grow—it is in my view now a seedling—and contribute to a more truthful understanding of nature.

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