In Context

Number 32 Fall 2014

The Newsletter of **The Nature Institute**

#32

Dear Friends,

Walking through the brightly colored New England countryside on a sunny day in autumn, one can hardly help feeling the almost overwhelming warmth and expansiveness of nature. The sense of richness is matched only by the awareness of rapid change. It is a time of gratitude and thanksgiving, which in turn are the ideal preparation for the reception of new possibilities.

There are moments when nature seems to mirror one's personal, social, or institutional circumstances with unusual fidelity. It is easy for us to feel this now, given the expansiveness and change—the abundant potential coming to fruition—here at The Nature Institute. If, as it could easily seem, we are indeed entering a new phase of the Institute's existence, perhaps a key signpost marking the beginning of this phase will prove to have been the completion of our building expansion.

In any case, for the better part of a year now we have been "taking hold" of the new space and putting it to use. Meetings, lectures, and workshops have recently been multiplying, and anyone who periodically checks our calendar (http://natureinstitute.org/calendar) will have noted that our educational offerings are now coming at a more rapid clip than ever before. So, too, with our educational outreach nationally and internationally. Craig, for example, has recently returned from teaching a course at Schumacher College in England. And now, as you will find on page 10, we are offering our first "nature adventure" to a distant part of the globe—an educational journey to the Amazon River basin.

Change and enrichment can take many forms, including a broadening of one's focus of attention. Henrike has undertaken a research trip to the Exploratorium in San Francisco. (The article on page 3 offers just a hint of her conclusions from that trip, which occurred in collaboration with two colleagues, one from Germany and one from California.) In response to external requests, Craig, a biologist, has found himself pursuing questions relating to technology—a field Steve was specializing in when he joined the Institute in 1998. Steve, in turn, continues his investigations in molecular genetics, which was strictly "Craig's field" in those early years. The twists and turns of life's pathways can be full of surprises.

Our current sense of change and new potential, of course, is dramatically magnified by the presence of a new colleague, Bruno Follador (page 13). Hailing from Brazil and deeply identifying with the mission of The Nature Institute, Bruno will direct a new project area we are calling *Living Soils*. You can expect to hear more about this in the future.

Finally, it is always good to enter into the worthy work of others and to offer support for it where that is possible. It might be hard to find any work more clearly worthy of such support than that of the late philosopher, Ronald Brady. His publications deserve vastly more exposure than they have yet received, and we are now engaged in a project aimed at securing such exposure (page 9).

All in all, it's a stimulating time to be working here at The Nature Institute! For this we are enduringly thankful to all our friends who make the work possible.

Craig Holdrege — Steve Talbott

Craig Holdrege — Steve Talbott

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

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Exploring the Exploratorium in San Francisco

Henrike Holdrege

On three consecutive days in April 2014, two colleagues and I visited the Exploratorium in San Francisco, California. Founded in 1969, this "Museum for Science, Art and Human Perception" is highly acclaimed world-wide for its exhibits that allow visitors to engage in hands-on and self-guided explorations of science. The exhibits are meant to be educational, informative, engaging, fun and entertaining. Our intention was to fully participate in what the museum offers and to assess what we encountered. Here are some of my observations and reflections.

A visit to the Exploratorium is self-guided. No museum staff will prevent you from making your own choices nor will they help you make good choices. Walking into the large hall, you follow the path you choose and you meet, with only a few steps in between, exhibit after exhibit. Some of them have a quiet appeal, some of them are flashy. This creates an immediate hurdle to meaningful learning. Sue Allen, who conducted visitor research and evaluation as an Exploratorium employee for over a decade, described the problem this way:

> Science museums are actually very difficult environments to engineer for learning… On the exhibit floor there is no accountability, no curriculum, no teachers to enforce concentration, no experienced guide to interpret and give significance to the vast amounts of stimulus and information presented. Without restrictions, visitors have complete freedom to follow their interests and impulses as they move through a public space packed with exhibits all vying for attention. (Allen 2004)

Exploratorium visitors interact with exhibits.

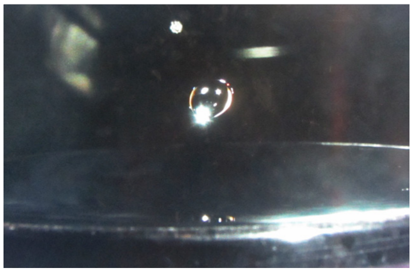
Staying focused

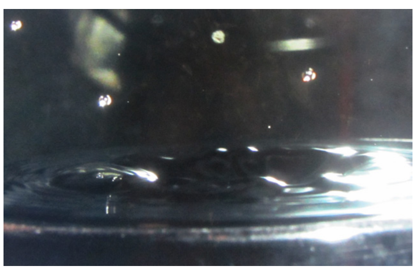
We found it important to voice and hold onto our own interests; without this we would get side-tracked, lose control over our explorations, and quickly tire. Over those three days, we consciously limited ourselves to certain parts of the museum. We stayed with exhibits on physics and human perception, and on the second and third day concentrated mainly on acoustics.

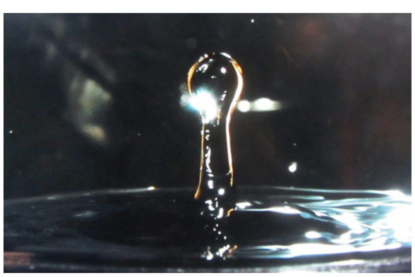
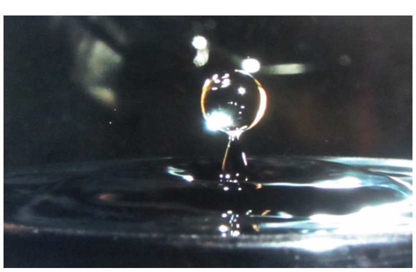
Even with a restricted focus it was easy to feel overwhelmed. This is known to be a frequent experience among visitors. As Allen observed:

> The effort it takes to negotiate a museum is apparent through the common phenomenon of "museum fatigue," in which the visitor can only engage deeply with exhibits for a limited period (typically about 30 minutes) before they lose their focused attention and begin to "cruise," looking for anything particularly compelling before moving on. Museum fatigue is an important factor that limits the degree to which visitors can effectively learn any form of science.

Each day we managed about four to five hours of wakeful activity at the museum. We engaged with exhibits, trying to understand what they demonstrated, how they were designed, and how they functioned. We observed other visitors engaging with exhibits. During breaks we shared and discussed our observations and our critiques. Our own motivation and intentional activity helped us to stay focused and resist "museum fatigue."



Those exhibits where I stayed for a longer time are the ones that I remember now and that fatigued me the least. When my long-held interests and questions were met or I came across novel aspects of topics that interest me, I was delighted and worked to gain a more thorough understanding. When, however, an exhibit related to things I had never concerned myself with, I did not always find an extended visit worthwhile.

In many cases it was helpful simply to ignore the interpretative texts accompanying exhibits. The explanations, I found, were rarely phenomenological. For instance, the caption next to the display of the brain of a deceased human being said "It is all in your brain." This dogma is reiterated at the Exploratorium over and over again in the exhibits relating to human perception. I sustained my interest in the phenomena on display by being aware of those theoretical constructs and not letting them guide and limit my own insights.

Interactions with exhibits can be fascinating

I was delighted to find in a quiet corner an exhibit that allowed me to photograph a falling drop of water and its impact on the surface of a cup brimful with water. The visitor sets the time when the photo is to be taken (in milliseconds after the drop release) and then releases the drop by pushing a button. Shortly after, the photo is displayed on a large screen. I took a series of photos: a drop falling, hitting the surface, and then a breathtaking unfolding of water movement — uprising, sinking, and uprising again — in intricate forms of great beauty. Behind me, other visitors watched patiently until I felt I had to move on.

This exhibit is one of many at the Exploratorium that allow a person to make observations that other teaching institutions (for instance high schools or colleges) cannot easily provide due to the exhibit's cost. In many cases I admired the ingenuity that went into the design of an exhibit, its elegance, durability, and professional craftsmanship. Exhibits here have to be robust in order to withstand misuse by children or adults. Most of the ones we engaged with functioned as they were intended, but some were broken and needed repair.

A simple exhibit awaits the visitor at the start of the acoustics area. A long sturdy rope hangs loosely under the high ceiling, fastened at both ends. A second rope is tied to this "giant guitar string", as it is called, and hangs down within reach of the visitor. By pulling this rope rhythmically you can set the "guitar string" into wavelike motions which will, with some skill on the user's part, result in a stationary wave. After practicing awhile, I managed a rather lopsided stationary wave.

The next exhibit in the acoustics section demonstrates air oscillation in relation to pitch: a metal pipe with a bore hole functions like a wind instrument. A constant stream of air is provided, and in a user-friendly way the visitor can adjust the pitch. Through an arrangement of a light beam and lens on the left and a screen on the right, the air movements above the bore hole are made visible on the screen as shadow-like, rhythmic, dancing oscillations. Their rhythm is faster when the pitch is higher and visibly slows down when you lower the pitch.

Further down the hall there are three Chladni plates. The first one is an impressively large thin square metal plate, about a yard in length. It is encased in a transparent box, connected to a microphone into which you can speak or sing. When I came across the exhibit, a young man was rapping into the microphone. Nothing happened on the plate. When he left I took the microphone and sang a single tone over a longer period of time. In those areas where a thin layer of fine sand covered the plate, an intricate sand pattern began to form. When I changed the pitch, the pattern gradually reworked itself into a different form.

Next to this plate are two smaller Chladni plates, a round one and a square one. With these you can induce vibrations by forcefully pulling a bow alongside their edge. I sprinkled one lightly with sand, and then my continued bowing resulted in a sand pattern. Lowering my eyes to the level of the plate I saw the sand kernels bouncing off the plate in some places and coming to rest in others, thus forming the pattern. We showed a staff member how to work the plates and for the first time, as he admitted, he delighted in producing a sand pattern himself.

How does a child learn?

On Friday, the last day for us, we arrived at mid-morning and the museum hall was crowded with school children, from elementary through middle school. This obviously was the day for school field trips to the museum. The noise level was high.

A staff member had already told us "Nowadays children are often warned 'Don't touch this or that!' Here, at the museum, children are allowed to touch things." And this is what they did. "Plates are for pushing. Knobs are for turning. Slots are for inserting things into. … the user knows what to do just by looking: no picture, label, or instruction is required. Complex things may require explanation, but simple things should not" (Donald Norman, cognitive scientist, cited in Allen 2004). The children walked or rushed from exhibit to exhibit, excited to push, pull, or turn whatever they could put their hands on. Their teachers had an eye on them, but rarely gave guidance.

Most students seemed to have fun. But what did they learn that day about science, about the world? What memories did they form? What interest or motivation was sparked in them? What wonder was aroused?

On the Chladni plates that day, I repeatedly reworked a pattern so students would see it. Each time I returned, sand lay in thick layers on the plates, although the sign reads: "It works best with only a little sand." A child sang into the microphone. I told her and her mother about the secret of holding one tone. The girl was delighted when the magic worked and a sand pattern appeared.

I observed students at the "wind instrument" that I described earlier. They pushed the rod that regulates the pitch and then moved on. Like many adults on the previous day, they did not notice the screen to the right and missed the sophistication of this exhibit.

When I came to the water drop exhibit for a second exploration, I surprised two children who at that moment were attempting to shake the whole enclosure that protects the exhibit. They obviously were desperately looking for something they could put their hands on.

On my way back to the acoustics exhibition I passed by one of my favorite exhibits: heavy metal balls hang in one long row suspended from strings of varying lengths, the lengths getting shorter and shorter according to a mathematical law. Set simultaneously into motion through a simple mechanism, each pendulum swings at its own rhythm and together they show a wave form that metamorphoses. At that moment a boy was playing with the pendulums. I stopped and showed him what he could do. I called on his patience to watch the changing wave pattern closely. He enjoyed what he saw and continued when I walked on.

When I arrived at the "giant guitar string" exhibit, its function was being wholly transformed by two girls. The rope "for pulling" had changed into a rope "for climbing." They attempted to climb up that rope, with some success and no harm done.

At this point I saw clearly: This is not meaningful science learning. What these children need is the great outdoors or an adventure playground where they can engage hands-on with the elements; where they can play and experience, unhindered; where they can learn through their own activity, creativity and involvement; where they experience the world as young and fresh as they themselves are in their young lives; where their engagement with the world is free from and not constricted by the views of an already existing scientific establishment.

And later, from elementary into middle school and on, I wish for them a carefully thought-out, age-appropriate, and phenomenological science curriculum that can further their own curiosity—one that lets their interest in, and understanding of, the world grow in ever widening and deepening circles that can keep growing even when they get to be old and wise women and men.

Reference

Allen, Sue (2004). "Designs for Learning: Studying Science Museum Exhibits That Do More Than Entertain," *Science Education* vol. 88 (Suppl. 1) pages S17-S33. Available online: http://xa.yimg.com/kq/groups/28001072/1514719950/name/Allen_Exploratorium.pdf

Evolution as a Movement Toward Autonomy

On the Origin of Autonomy by Bernd Rosslenbroich (Springer Verlag, 2014), 297 pages, 61 illustrations

Reviewed by Craig Holdrege

One-celled protozoans, jellyfish, sea urchins, squids, swordfish, and dolphins are all wonderfully adapted to life in water. But that fact tells us little about how each of these creatures lives its life. All these animals are organized differently from each other—they belong to different phyla or classes—and the way they are organized lets them interact with and create environments and relations that are unique to each. They all have "ways of being." According to conventional Darwinian evolutionary theory, the animals have evolved and survived because they are well-adapted to the circumstances in the environment (this is called natural selection). But natural selection does not account for the unique forms and organization of different animals. It can only interact with what is already existent and "weed out" what is not adapted.

So where do all the "endless forms most beautiful and most wonderful" (Darwin) come from? Conventional theory says that through genetic mutations, recombination of genes and, more recently, epigenetic changes arising out of organism-environment interactions, new characteristics arise and are then passed down to subsequent generations. This kind of thinking "explains" characteristics through the supposed mechanisms that brought forth the traits. The characteristics in and of themselves—and therefore also their mutual relations within the organism and their relations to the characteristics of other organisms—are considered to be the fortuitous by-products of the evolutionary mechanisms. On this view, it is enough to propose a plausible mechanism and then describe how any given feature of the organism—the long neck of a giraffe, the color pattern of a grasshopper, the hard shell of a mussel— is a "survival strategy" and as such contributed to the survival of the species.

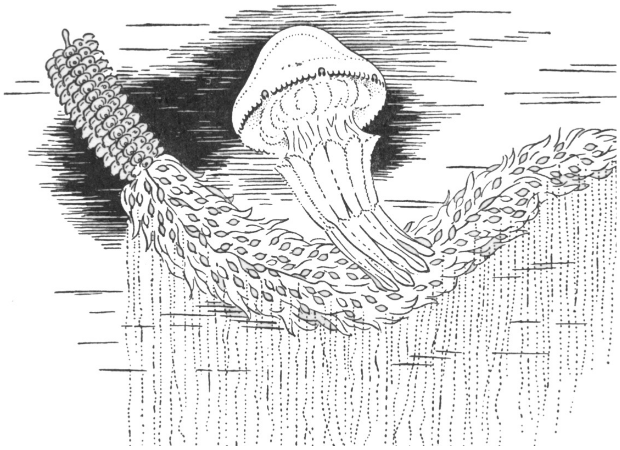
There is, of course, no necessity to "explain" organismic evolution in this way, and it does not provide insight into organic forms as such. New vistas open up when one lets go the idea of mechanism-as-explanation and begins to look at the phenomena in their mutual relations. In *On the Origin of Autonomy,* Bernd Rosslenbroich—who is head of the Institute of Evolutionary Biology at the University of Witten/Herdecke in Germany—takes a step in this direction. He presents a wealth of biological facts that point to a significant, overarching evolutionary pattern: "a recurring central aspect of macroevolutionary innovations is an increase in individual organismal autonomy whereby [the organism] is emancipated from the environment with changes in its capacity for flexibility, self-regulation and self-control of behavior."

This pattern or trend has been discussed by Goethean biologists Kipp, Schad, Suchantke, Verhulst, and others, and it is a pattern that has been recognized periodically by mainstream biologists. Rosslenbroich's contribution is, first, to show that a certain degree of autonomy can be discovered as a basic characteristic of life, and then to trace in great detail and breadth the countless metamorphoses and intensifications of autonomy in the entire animal kingdom. (He does not deal with plants in this book.)

For example, Rosslenbroich contrasts (Chapter 4.2) the organization of prokaryotes (bacteria and archaea) with the cellular organization of eukaryotes (all other organisms). All biology students learn the difference between these two types of cellular organization: DNA in prokaryotes is not enclosed by a membrane, which is the case in the nucleus of eukaryotic cells; prokaryotic cells are generally much smaller than eukaryotic cells; and so forth. But these facts are generally not viewed within any larger context, which is what Rosslenbroich looks for. He describes how the differing characteristics show an increasing degree of internalization and internal differentiation of organization. Prokaryotes easily exchange genetic material with one another (calling into question the species concept for this group of organisms). In feeding, they are "dependent on the uptake of dissolved substance across their membrane," secrete enzymes into the surrounding medium, and have, therefore, "external digestion." They are (usually) tiny and have a very large surface area in relation to their volume, so that they are essentially surface organisms interfacing with their surroundings.

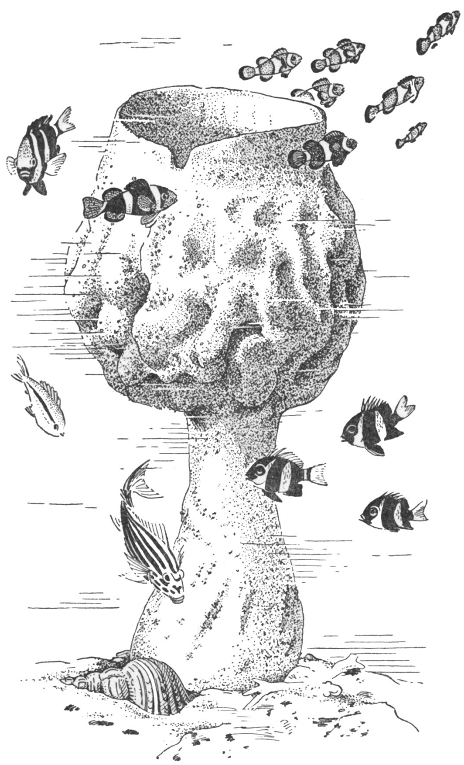
In contrast, eukaryotic cells have more stable genomes and their nucleus is enclosed within its own nuclear envelope. They have distinct membrane-enclosed organelles such as mitochondria and chloroplasts. There is a cytoskeleton that provides internal mechanical support for the cell. Digestion occurs within the cell. And their larger size means there is a "reduction of relative surface area, thus reducing the direct contact to the environment relatively."

Through Rosslenbroich's detailed and integrative comparison the reader can form a dynamic picture of a process of internalization and compartmentalization of organismic



functions. Since both types of organisms thrive on the planet, the differences do not indicate that eukaryotic cells are in any way better adapted than prokaryotes. The differences are qualitative and point to different ways of being—one showing remarkable embeddedness and responsiveness to the immediate fluid environment and the other moving in the direction of greater self-encapsulation.

In presenting autonomy as an evolutionary trend, Rosslenbroich does not try to make a neat scheme. It is clear that the evolution of the "animal organism" is not linear. He presents, for example, the feature of viviparity—giving birth to live young— which is a telling case of internalization of embryonic development into the maternal organism that is typical in mammals. And yet there are many examples of viviparity in other vertebrate classes (for example, fishes and reptiles). There are even some fish with placenta-like formations in the female body. You begin to get the sense of how the trend toward internalization is in a way spread throughout the animal kingdom and becomes embodied in partial and unique ways in different groups. What may appear almost as an anomaly or exception to the rule in one group becomes a central feature in another.



Released by the academic publisher Springer, the book is written for a mainstream academic audience. The style is dry and the author also adapts, it seems to me, to the expectations of mainstream thinking by framing autonomy sometimes as a "theory" and sometimes as a "hypothesis"—rather than, to use Gregory Bateson's phrase, as "a pattern that connects." He also gives a fair amount of space to the discussion of how biologists try to explain (by proposing mechanisms) the emergence of autonomy traits in evolution. I found these sections of the book least interesting, since they are basically a collection of speculations. *Understanding* evolution—which entails an ever deeper recognition of patterns and relationships—is not the same thing as speculating about mechanisms (Brady 1983), an activity that has unfortunately become all-too dominant in evolutionary biology.

Overall, though, the book is a treasure trove for biologists and biology teachers. It not only offers a wealth of examples that would be hard to find elsewhere, but also provides new contexts of understanding that can help shed light on many biological phenomena that otherwise remain isolated pieces of information.

Notes

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Drawings from A. Portmann

Let's Loosen Up Biological Thinking!

Stephen L. Talbott

Think of this brief "editorial" as the commentary piece that the editors of journals such as Nature, Science, *and* Cell *cannot yet write due to the reigning taboo. Sooner or later, however—compelled by ever mounting biological evidence—they will write their own versions of this article.*

Nine years ago Richard Conn Henry, an astrophysicist at Johns Hopkins University, published an opinion piece in *Nature* entitled "The Mental Universe." He urged the scientific community to repeat Galileo's achievement in "believing the unbelievable," and recalled Sir James Jeans' famous remark that "the Universe begins to look more like a great thought than like a great machine." We don't know all that this implies, he continued, "but—the great thing is—it is true … The Universe is immaterial—mental and spiritual. Live, and enjoy."

The most dramatic thing about the article was the lack of drama: it produced no visible controversy. After all, physicists have long been accustomed to receive such assertions peaceably, because the science itself seems tolerant of them.

But suppose Henry had made a narrower and more modest claim—just a small part of what he implied in "The Mental Universe." Suppose he had written only of "The Mental Cell." Would the occasion have been equally unremarkable? Most molecular and cellular biologists, I suspect, will readily picture the unseemly consequences likely to follow upon the appearance of words like *immaterial*, *mental*, and *spiritual* in their published papers. It would be as if an unspoken taboo were violated.

It seems ironic. Physicists, students of the *inanimate*, have long been free to speak of mentality—for example, the mental activity of the observer in quantum experiments. Biologists, students of *life* (and, all too often, enviers of physics) have hardened in their resistance to such language.

Or have they? It depends on what you look for in their literature.

An outsider could be forgiven for thinking that the "mindful organism" is what biology is all about today. Even molecular biologists speak about sensing, signaling, and well-gauged responses. They describe calculation and the pursuit of ends; communication and the sharing of information; efficacious or harmful folding of proteins; correction of errors in DNA replication; and, more broadly, adaptation, behavior, and the performance of complex tasks such as cell division or RNA splicing.

Streams and volcanoes do not signal each other or correct errors, they do not respond to stimuli, and they do not carry out tasks. That the characteristic language of biology suggests some sort of mindfulness—for example, cognition and the purposeful or intentional coordination of means toward the achievement of ends—is not controversial. Any controversy has for several decades been stifled by a widespread expectation that the discomforting language is somehow inessential and on its way to being "naturalized."

Despite ongoing and even intensifying usage that seems to belie that expectation, a common line of thought runs this way: "Yes, there is an appearance of mindfulness in all organisms, but this is a *mere* appearance, or an *illusion*. And the explanation for the illusion is natural selection." The idea is that variation plus selection results in adaptation, and adapted behavior possesses a functional effectiveness that looks *as if* it were mindfully guided.

Not all those who say such things would be willing to describe their own minds and intentions as illusions. But, in any case, we are left to wonder how an organism's apparently purposeful activity is explained by similar activity in previous generations. Selection, after all, requires organisms that grow, develop, compete, prepare an inheritance, produce offspring, and otherwise pursue their seemingly intentional and well-directed lives, judiciously improvising all the way. These are the very activities that raise the *question* of mindfulness. So how does weaving the lives of many such organisms into the infinitely complex narratives of natural selection *explain* this mindfulness?

Many biologists are content to dismiss the problem with hand-waving: "When we wield the language of agency, we are speaking metaphorically, and we could just as well, if less conveniently, abandon the metaphors."

Yet no scientist or philosopher has shown how this shift of language could be effected. And the fact of the matter is just obvious: the biologist who is not investigating how the organism *achieves* something in a well-directed way is not yet doing biology, as opposed to physics or chemistry. Is this in turn just hand-waving? Let the reader inclined to think so take up a challenge: pose a single topic for *biological* research, doing so in language that avoids all implication of agency, cognition, and purposiveness.[1]

One reason this cannot be done is clear enough: molecular biology—the discipline that was finally going to reduce

(continued on p. 23)

The Ronald H. Brady Archive

We are pleased to announce a project, already underway, to make available on our website the published work of philosopher Ronald H. Brady.

Throughout his productive scholarly career, Ronald Brady concerned himself with the philosophical foundations and practice of phenomena-centered science. He made substantial contributions to the study of evolutionary morphology and systematics, while also pursuing fundamental issues in epistemology. His 1987 elucidation of "Form and Cause in Goethe's Morphology" may count among the most decisively revealing biological papers of the past several decades — one that the science has yet to catch up with.

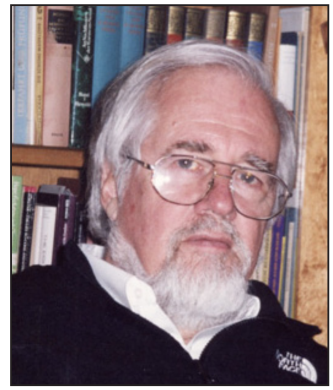
At the time of his death on March 27, 2003, Brady was a professor of philosophy teaching in the School of American and International Studies at Ramapo College, Mahwah, New Jersey, having joined the school's faculty in 1972.

We are now working on The Nature Institute's "Ronald H. Brady Archive" project, with the intention of putting online as many of Brady's published scholarly works as possible. The currently available titles are listed below. The project is targeted for completion by June 2015.

Brady told this story about his undergraduate days:

> When I began college as a chemistry major my enthusiasm for science was somewhat dampened by meeting a professor of chemistry who pointed out the difference between my own goals and those he, as an experienced professional, would call mature. My passion, he noted, was entirely focused on direct experience — my sense of chemical change was invested in sensible qualities: in smells, colors, the effervescence of liquids, the appearance of precipitates, the light and violence of flame, etc. But, he countered, this was probably closer to medieval alchemy than to chemistry. The latter is really a matter of molecular and atomic events of which we can have only a theoretical grasp, and the sensible experience on which my excitement centered was secondary . . . I was reminded of him when I spoke to a morphologist at Berkeley about my interest in Goethe's attempt to approach science by keeping to direct experience. The morphologist responded: "You are interested in this approach because you are a Nature appreciator, while I am a productive scientist." It is always nice to see where one stands.

We think Ron would agree that much of his career was devoted to understanding the views of those college mentors — and also recognizing their limitations. Happily, the fruits of his work are now becoming conveniently available. We have recently added three papers to the five publications already available on our website. These three deal with problems relating to form, biological classification, and the nature of biological explanation in relation to biological description:



- "Form and Cause in Goethe's Morphology" (1987)
- "Pattern Description, Process Explanation, and the History of the Morphological Sciences" (1994)
- "Explanation, Description, and the Meaning of 'Transformation' in Taxonomic Evidence" (1994)

Here are the other publications by Brady currently accessible via our website:

- *Being on Earth: Practice In Tending the Appearances* (2006), a book by Georg Maier, Ronald Brady, and Stephen Edelglass. Brady's chapters are entitled "Direct Experience" (chapter 1), "Intentionality" (chapter 4), and "Manifestation from Inside Out" (chapter 8).
- "Dogma and Doubt" (1982). This paper explores the role of evidence and belief in the doctrine of natural selection.
- "Getting Rid of Metaphysics" (2001). Here Brady argues that, because science fails to recognize the mind's participation in the world it investigates, "scientific thinking is limited to a form of thought that cannot question its own premises."
- "The Global Patterns of Life: A New Empiricism in Biogeography" (1989). This essay disentangles the role of observational evidence and "pseudo-phenomenal events" in biogeographical explanations. (Biogeography is the study of the distribution of the ranges of plants and animals.)
- "Perception: Connections Between Art and Science." What is the role of thinking ("intentionality") in the perceived world?

We will complete the project, which includes a further half dozen papers, by June 2015. You will find the up-to-date archive at http://natureinstitute.org/txt/rb.

We thank the Foundation for Rudolf Steiner Books, Mahle Foundation, R. Steiner Fund for Scientific Research, and Waldorf Educational Foundation, whose generous support made this project possible.

Form and Pattern in the Amazon

June 1 to June 12, 2015

An invitation to a journey of discovery




Photos by Mark Riegner from previous Amazon trip

Join Prescott College environmental studies professor Mark Riegner and Nature Institute director Craig Holdrege on a twelve-day expedition in the Brazilian Amazon that will apply methods of observation grounded in the view of nature developed by the influential poet and scientist, J. W. von Goethe. This trip will be especially valuable to Waldorf teachers, other educators, nature lovers, artists, and anyone who has an interest in holistic science.

Mark and Craig are long-time colleagues and have decided to team up to co-lead this exciting nature tour that will be tailored to those with an interest in holistic approaches to science and the discovery of patterns in nature. Mark teaches, among other things, ecology field courses in Mexico and Costa Rica, and is author of numerous articles that explore form and pattern in animals as well as the philosophical basis and practical application of Goethe's way of science. He has previously led a tour with this same itinerary.

We will focus on plant morphology and metamorphosis, as well as on form and pattern in mammals and birds. In preparation, and during the trip, we will read and discuss articles and book excerpts by Craig on the practice of Goethean science, plant metamorphosis, and the nature of the sloth (of which we hope to see a few!), and by Mark on Goethe's way of science, form and pattern in mammals, and bird form and color pattern. We will train ourselves to observe nature carefully, using various tools such as clear description, discussion, sketching and other artistic activities, and daily reviews, while also seeking patterns of relationships among the many nature observations we make. We will practice the skill of observation essential to Goethe's holistic way of science and thus try to imagine, and even emulate, how the great poet and scientist would have experienced nature in the Amazon Basin.

We will spend eleven days cruising the Amazon, Solimoes, and Negro rivers and their tributaries aboard our private chartered ship, the *L. V. Dorinha*, operated by Amazonia Expeditions (http://amazoniaexpeditions.ning.com/). Each day, we will explore river tributaries, oxbow lakes, and other channels in small, motorized canoes. Highly skilled boatmen will take us out early in the morning for bird watching and wildlife viewing. In the evening we will explore wildlife with spotlights from the canoes. June is high-water season and will allow us the greatest opportunity to enter deep into the forest by boat and possibly glimpse animals of the forest canopy.

Although we will have a full schedule, this is a relaxing trip. We can settle into our rooms (2 people/room, bunk beds, private bathroom w/shower, air conditioning), unpack just once, and allow the boat to move us every night to a new locale. The seven-person crew is extremely hardworking and very friendly, and will do everything they can to make this trip the best it can be for all on board. We will enjoy an array of fresh foods, local produce, and freshly caught fish (vegetarian diets can be easily accommodated). We'll have the choice to eat in a comfortable dining room furnished with local hardwoods, or enjoy the breezes of the open-air upper deck. Mark and Craig will be available to provide insights into the flora, fauna, and ecological relationships that we'll be encountering along the river. In addition, our captain and some of the crew are experts at locating and identifying wildlife.

We have set the cost of the trip as low as possible. Estimated cost/person (including all accommodation and meals, boat transportation, airport pick up, park entrance fees, etc.):
US $2,900 (up to 13 participants, 10 minimum) from Manaus
US $2,800 (14/15 participants) from Manaus
US $2,700 (16 participants) from Manaus (16 is maximum)
(Note: airfare and Brazilian tourist visa are not included. Participants will make their own travel arrangements to Manaus, Brazil.)

For more detailed information, description, and logistics, please see the Nature Institute website: http://natureinstitute.org/educ/2015_amazon.htm.

We will also provide regular updates through the link. We hope to have commitments by mid-December.

If you have any questions, please contact Mark at mriegner@prescott.edu. We hope you'll join us in the Amazon!

Highlights from Our Summer Courses

In our summer course on "Reading in the Book of Nature" we prepared ourselves each morning with geometry exercises designed to enliven thinking and imagination. Henrike led us in the development of Cassini curves that show a surprising metamorphosis of form. Then we turned to plants. We studied dogbane (*Apocynum cannabinum*), a plant that grows in our old fields. A number of participants noticed that it in some ways resembles milkweed, so we also compared it with the common milkweed and worked to articulate its characteristic features. The transition from carefully taking in all the details to seeing certain qualities or gestures that characterize a plant is the beginning of "reading in the book of nature."

Later in the week we considered the pea family (Fabaceae) and compared several different species with one another: white sweet clover, crown vetch, red clover, birdsfoot trefoil, yellow sweet clover, cow vetch, and hop clover. It was relatively easy, especially in the flower, to see a shared form and structure. But there was also a wonderful variety in overall plant habit and size, flower color and shape, the way the flowers are arranged on the stem, and in the leaf forms. We began to see in the family a characteristic potential expressing itself in manifold ways. We closed each day working with clay. Patrick Stolfo led us in exercises that further awakened our sense for form and transformation.

Over the course of three and a half days in August, Jaap van der Wal, embryologist and medical doctor from the Netherlands, gave a "performance" of "The Embryo in Us: Dynamic Embryology and Morphology." Jaap calls what he does a "performance" because he enters into the processes of development and transformation with his attention and imagination so that, in his speaking, gesturing, and the many images he shows, the processes can also come alive in the participants.

What becomes so clear through his presentations is how all form arises out of movement and how gestures and formative movements *performed* by the embryo prefigure later postnatal behavior. For example, the arms and legs develop out of small buds, but the arms grow out to the front in an embracing gesture, while the legs grow down in an extending, standing gesture. Jaap presented an astounding breadth of material and showed in an exemplary way that in order to understand any given detail of the formative process you need to, first, see it in its developing movements and, second, bring it into relation to a broad array of phenomena. Then its deeper significance begins to speak. Readers can go to his website (http://www.embryo.nl) and delve into the rich material he provides there.

Fall Events at the Institute

• **A Pathway to the Spiritual in Nature.** At the end of September Henrike and Craig led this weekend workshop in celebration of Michaelmas. The theme was introduced on Friday evening with a talk, "Overcoming the Cartesian Split." On Saturday and Sunday participants engaged in a variety of observations and exercises.

• **Teach-In on Techno-Utopianism.** Craig was an invited speaker at an October teach-in in New York City on "Techno-Utopianism and the Fate of the Earth," sponsored by the International Forum on Globalization.

• **Caring for the land.** In October we held a volunteer work day and did landscaping work on the grounds of The Nature Institute. Thank you to all who helped us prepare the land for winter!

• **Technology and us.** Craig held three talks on "Cultivating Humanness in a Technological World" in October and early November. Each talk was followed by conversation. The talks were based on the four talks he gave in June at the annual conference of the Association of Waldorf Schools of North America (see below under "Out and About").

• **Chasing the light.** Henrike is again giving a course on light and color for the art students of Free Columbia. The expanded facilities at The Nature Institute allow the teaching to be easy and effectual.

• **Math in the upper grades.** In early November we hosted a weekend workshop for middle and high school math teachers: "The Tyranny of 'Algebra I': Reimagining Math Curricula." This weekend was an initiative of Marisha Plotnik, a math educator, mentor of teachers, and new Nature Institute board member, and Beth Weisburn, a high school teacher at the Summerfield Waldorf School in Sebastopol, California.

Henrike also contributed to and participated in the workshop. When she recognized the abstractness in existing Algebra I textbooks, Henrike realized why so many students fail in math. So a goal of the workshop was for teachers to help each other find true inspiration toward shaping an integrated, more meaningful and age-appropriate Algebra curriculum.

• **"Nature's Gestures in the Cycle of Dying and Becoming"** is the topic of a weekend workshop in mid-November. For the first time Henrike co-teaches with Penelope Baring, who has worked and taught within the Camphill movement around the globe. Their aim is to integrate contemplative practices and exercises in wakeful sense perception to gain a deepening understanding of the world we live in and the role we play in it.

Out and About

• **From compost to freedom and cognition.** In November Craig and Bruno Follador—who has just joined our staff to direct a major new project, *Living Soils*—are leading workshops at the 2014 North American Biodynamic Conference in Louisville, Kentucky. Bruno's workshop focuses on "Composting as a Free Deed: Being and Becoming." Craig is leading a half-day pre-conference workshop on "A Goethean Approach in Biodynamic Education and Mentorship," and also a workshop in the main conference on "A Way of Knowing as a Way of Healing."

• **Thinking like a plant and sauntering like Thoreau.** Craig was invited by William (Bill) Vitek, Professor of Philosophy and Chair of the Department of Humanities and Social Sciences at Clarkson University in upstate New York, to give a public talk there in late October related to his book *Thinking Like a Plant*. The next day, along with Bill, he co-led a seminar for professors and students on Thoreau's practice of "sauntering" as a way of knowing. They also dealt with Thoreau's idea of "wildness."

• **Activities in England.** In September Craig was in England for ten days. He taught for a week in the Masters of Holistic Science Program at Schumacher College. His topic: "A Practical Introduction to a Goethean Way of Science." Craig also gave a public talk on "What is Education For?" at the South Devon Steiner School and led a one-day plant study workshop. This, by the way, was the week of the vote on Scottish independence, so Craig had a ringside seat amid the politically intense activities of that week.

• **Teachers and technology.** Craig was the keynote speaker in June at the annual conference of the Association of Waldorf Schools of North America, which was attended by more than 200 teachers and administrators from Waldorf schools in the U.S., Canada, and Mexico. He gave four talks on the conference theme, "Cultivating Humanness in a Technological World." Craig strove to create an awareness for the ways in which technology is infused into our modern lives and how it both connects and disconnects us from the larger world. To ensure that we don't get lost in a world of devices, he emphasized, we need to become increasingly aware of ourselves as beings participating in a world of beings. The concrete relation to the sense world and all its qualities is here essential. Participants enthusiastically received that message. For example, one teacher with an advanced degree in computer information systems wrote afterwards, "I think these were some of the most powerful presentations I have ever listened to, and will actually be life changing for some of us (certainly, for me!)." *We plan to make recordings of the talks available. Please watch our website for forthcoming information.*

• **Providing context for a UN advisory group.** At a special June workshop in Montreal, Craig spoke about the risks that *synthetic biology*—an extreme new form of genetic engineering—poses to biodiversity. The workshop was organized to brief official delegates serving on the United Nations' influential scientific advisory group for the Convention on Biological Diversity, as well as civil society groups that advocate strengthening that international treaty. Craig was asked to provide a contextual critique of assumptions that synthetically engineered organisms can be made to act like controllable and predictable machines. To learn more about synthetic biology, see Craig's feature article in this issue.

• **Out and about in print.** Craig was invited to write a chapter on "Why Context Matters" for a new book, *The GMO Deception: What You Need to Know about the Food, Corporations, and Government Agencies Putting Our Families and Our Environment at Risk.* (Edited by Sheldon Krimsky and Jeremy Gruber; New York: Sky Horse Publishing, $24.95, 357 pages.) To read a review of the book by our outreach director, Colleen Cordes, go to: http://natureinstitute.org/nontarget/misc/gmo_deception.php.

Also, a new book has appeared with a chapter about Craig. For details, see "A Dialogue with the World" on p. 14.

Still Ahead

Will you be within trekking distance of any of these events?

Developing a Qualitative Understanding of Nature: Animals, Humanity, and Evolution (At The Nature Institute). A course offered February 8-13, 2015, in collaboration with Hawthorne Valley Farm and the Biodynamic Association of North America.

Science rooted in experience (Sebastopol, California). In late February, Craig and Henrike will be in California attending a conference for middle and high school teachers, "From Phenomena to Insight." The event is sponsored by the Center for Contextual Studies at the Summerfield Waldorf School in Sebastapol. Craig will give four presentations about the foundations of phenomenology and experience-based science. He will also give a workshop for biology teachers at the conference, which runs February 17-21, 2015.

Geometry and plants (Los Angeles). February 27 to March 1, Henrike and Craig will lead a public workshop sponsored by the Pasadena branch of the Anthroposophical Society on "Developing Living Thinking: Projective Geometry and Plant Study."

Mathematics Alive! – The Platonic Solids (At the Nature Institute). The weekend of April 10-12, 2015, Henrike Holdrege and Marisha Plotnik will explore the geometry of the five Platonic solids and their relevance for the adolescent student from a variety of points of view. Hands-on work and movement, drawing, imagination exercises, and collegial exchange will all be part of the weekend.

International teacher training (Kassel, Germany). In early spring Craig will teach a five-day course to high school teachers and high school teacher trainees at the International Refresher Week of the Institute for Waldorf Education. The program is attended by teachers from around the globe. His topic is "Evolution as Metamorphosis." He will also give a talk for all conference participants entitled "Does the Giraffe Have a Long Neck? The Challenges of Holistic Biology."

Adventure in learning (On site in the Amazon Basin). Let your imagination embrace what you may never have considered before. Could the wonders of the Amazon River basin be in your future? See p. 10.

Welcome to our New Colleague

In October Bruno Follador joined The Nature Institute as a full-time colleague. A Brazilian, Bruno is deeply connected to the Goethean approach to science and is passionate about cultivating healthier interactions with nature in agriculture. He studied geography in Brazil and has trained in biodynamic farming. He recently worked for three years in Germany in farm-scale biodynamic composting. He has extensive experience as a farm consultant and is expert in qualitative methods for assessing soil and compost quality. His approach is rooted in the work of Ehrenfried Pfeiffer, a biochemist and agronomist who pioneered organic and biodynamic farming methods.

Bruno will develop and direct a new project we are calling *Living Soils*. Its broad intent is to stimulate holistic ways of perceiving and working with the farm as a dynamic organism and, more specifically, to integrate the development of high-quality composting into the life of the farm to improve soil fertility. Bruno will be working with farmers locally, regionally, nationally, and internationally. He will also hold workshops and continue research in holistic methods of assessing quality.

We welcome Bruno. You will be hearing more in the future about his work.

A Dialogue with the World

Michael Riordon, author of An Unauthorized Biography of the World *and* Eating Fire, *has written a new book entitled* Bold Scientists: Dispatches from the Battle for Honest Science. *The book includes a chapter with the above title, featuring interviews with Nature Institute director Craig Holdrege and reflections upon his work. Here are some excerpts from the chapter:*

"There was a time in the past when science actually meant more open inquiry, the search for knowledge," Craig continues, "but now it's become a very specific method you have to follow. And if you don't, it's not science. I don't see that as a higher standard, but a greatly reduced one. And a real problem."

We're sitting at a wooden table in the library/meeting room, sipping water from the institute's well. Through open windows I hear birdsong. But my brain is working hard here; I can almost feel it sweating. Although I'm accustomed to thinking and questioning, I don't know enough yet to fully fathom what Craig is talking about, but clearly it depends on learning to see—that is, to use our senses to find our way in the world—in a fundamentally new way. So I learn the way I usually learn, by asking more questions.

Craig spoke earlier about "the traps we fall into with our abstractions and theoretical constructs." What does he mean?

"I'll give you an example," he says. "If you look at biology in the twentieth century, it's been dominated by genes and genetics, the search for the ultimate cause of why organisms operate the way they do. Genetic science has been very successful in using reductionist methodology to find a substance, DNA, that plays a very important role in the lives of organisms." Reductionism is the belief that complex systems are nothing but the sum of their parts, and that to understand the whole, we need only understand the parts.

"But then there's been this overwhelming temptation to regard DNA as the ultimate cause," says Craig. "Think of the Human Genome Project: when we figure it all out, we will have basically deciphered the book of life. This is a very narrow view. Knowing the DNA sequence is only the beginning. We don't know how it's embedded in the nucleus within the cell, the cell within the tissue, and so on. Context gives meaning to genes. Finally in the past ten, fifteen years, geneticists are beginning to talk about this—the importance of context, the fact that genes need the whole to function. The new term is epigenetics."

A new term for an old new idea, apparently. Teaching biology classes in Germany and here at the Hawthorne Valley school, Craig would introduce the topic of genetics by talking about the plasticity of organisms. "If you take the seed of any plant, it can develop in many different ways, depending on context: the food it gets, light, soil, temperature, timing, all kinds of influences. If this process is plastic, meaning flexible, then it's not predetermined. There is no such thing as the leaf form. It arises over time, within a dynamic context. Of course there's a usual pattern for an oak leaf, different from the usual pattern of a maple leaf, but the pattern of each is quite fluid within boundaries. So then it becomes clear that the concept of the gene as a fixed entity is a high-level abstraction, not a biological reality."

Why is it a trap? At this point Craig introduces me to Kurt Goldstein (1878–1965), a German pioneer in neuropsychology. Goldstein argued that a central flaw in modern science is the tendency to ignore the problem of isolation.

"If you come to knowledge by isolating things—let's say the different components of a cell—you take them out of their natural environment, put them under a microscope, and you fundamentally change the conditions of their normal existence," he explains. "Kurt Goldstein said the problem with this is not that we do it, but that we forget we've done it. We abstracted the part from the whole, the larger reality, then we assume that what we learn from the process is in itself the actual reality. It's not.

"So this is the trap I see in abstraction. Human beings have this great ability to abstract, to stand back from things and explain them. This can be a gift, but when we substitute our abstractions for the real things, it becomes a problem. It's tempting to say that this is the cause of that. But then you have to ask, but within which context is it true? In one context it may be true, in another not. Goethe was keenly aware of this. He always wanted our perceptions to arise from a kind of dialogue with the world. From this perspective, knowledge is an organic process, less arrogant, more modest. It requires a certain amount of humility."

Not the best route to a Nobel Prize, I suspect, but it makes good sense in a world we're frantically breaking down into saleable parts, without anyone having a clue how to put it back together.

....

"The point is," says Craig, "we need to enter into conversation with other organisms to understand how each speaks from its own characteristics and the way it's related to the larger environment. Out of that we can weigh how our decisions are going to affect or interact with these animals or plants. I'm not saying we have to go back into the forest and live only from wild plants. We are manipulators in the world, we use our hands and brains to do things, and we interact whether we know it or not. Even if we ignore something, that's another way of interacting. So really it comes down to a question of being fully aware of what we're doing, and being fully responsible for it. I only wish these kinds of questions were part of science training, so students could learn to think about the consequences of what they're doing. Then at least they couldn't claim their approach is the only one they could take. It's tragic when they only encounter one way of seeing the world."

Bold Scientists was released this year by the Toronto publisher, Between the Lines. To find out more about the book and how to order, visit the publisher's website, http://btlbooks.com/book/bold-scientists.

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When Engineers Take Hold of Life: Synthetic Biology

Craig Holdrege

Scientists today are offering two entirely different visions of living beings. On the one hand, researchers are discovering the fluid, contextual nature of cellular and molecular processes in the organism from countless different angles, with considerable excitement. On the other hand—and with equal excitement—proponents of a relatively new discipline called "synthetic biology" are pursuing the idea that microorganisms, plants, animals, and human beings are machine-like systems consisting of context-independent parts. Synthetic biologists speak of "rationally designing," or reengineering, the organism to carry out functions that they and their funders deem worthwhile.

The fluid and contextual view of life is borne out by countless biological studies. For that reason we could wonder whether synthetic biology's focus on independent parts and its machine view of the organism—a view so little grounded in the biological reality of life—warrants serious consideration. But synthetic biology is propelled forward by highly intelligent and driven engineers and scientists and is funded and supported by large government grants and by venture capitalists who are led to envision myriad products coming down the pike. To be sure, we need to recognize that as a young discipline trying to sell itself to academia, businesses, and funders, synthetic biology can generate enthusiasm that is more or less detached from reality. But it is also true that one-sided and misguided ideas can have tremendous negative impact on the world. They warrant, therefore, careful consideration—and not only after the fact.

We can only hope that organisms themselves will be given due attention and that the shape of the future will not be determined by the free-floating fancies of grant-seeking, innovation-driven scientists and engineers. In the spirit of that hope, I begin with a brief look at what it means to be an organism.

A Power to Grow, Heal, and Adapt

Every healthy human being and animal has the remarkable capacity to heal wounds. When we are injured—cut, bitten, or burned—our body immediately responds. If the wound is not too massive, the blood clots, and a scab and new tissue, including blood vessels, begin to form. Within days or weeks, the healing process, which perhaps also results in the formation of scar tissue, is complete.

When biologists and medical scientists began looking into the details of wound healing at the cellular and molecular levels, they had cause to be amazed at, if not overwhelmed by, the complexity of all the relevant processes. And the more they have discovered, the more it has become clear that there is no "set" of processes, no defined "mechanism" of action in wound healing.

Take, for instance, platelets. As Leslie writes (2010):

> Thirty years ago, researchers were convinced that they had platelets pegged. Every milliliter of our blood, the thinking went, harbors hundreds of millions of these cell fragments for just one reason: to save us from bleeding to death. If we suffer a cut or other injury, platelets swarm into action, forming a plug that seals the wound.

As we now know, "in the absence of hemorrhage, platelets are not essential to wound healing" (Singer & Clark 1999). Moreover, platelets have many functions beyond their contribution to blood clot formation (Leslie 2010; Boyanova et al. 2011; Ware et al. 2013). They produce growth factors that promote healing and substances that help in the re-formation of damaged tissues. They influence the inflammatory response of the body to a wound and its innate immune response in a variety of ways. There are over 5,000 platelet proteins, and although platelets have no nucleus (and are in this sense "cell fragments") researchers have discovered that they do "contain a pool of mRNA which can be spliced and translated in a signal dependent manner" (Boyanova et al. 2011; see also Denis et al. 2005). What this means is that, depending on the substances platelets encounter in the wound environment, they form specific proteins that are effective in that particular situation. Since no two wounds are alike, the healing process varies according to the specific circumstances.

Another example. Connective tissue growth factor (CTGF) was so named because it was initially discovered as a substance that influences the growth of fibroblasts—cells that form connective tissue (Moussad & Brigstock 2000). Later it was shown to be involved in wound healing and the generation of new blood vessels. Over time, many more functions were discovered (Moussad & Brigstock 2000; Cicha & Goppelt-Struebe 2009). CTGF was found to enhance the growth of other types of cells, but also, under certain circumstances, to have negative effects on cell growth. Depending on the situation, during wound healing it can stimulate the generation of blood vessels, inhibit the growth of new blood vessels, or not be involved in blood vessel formation at all (Cicha & Goppelt-Struebe 2009). It becomes clear that the production and action of CTGF is "a function of the diverse environmental cues to which a cell is exposed at any point in time" (Moussad & Brigstock 2000).

It has become increasingly—we might also say, glaringly—clear that every cell type or molecule is much more multifunctional than originally thought. If researchers study, say, platelets in a particular experimental context, then they may get a fairly defined picture of what they might call "platelet function." But they should call it "platelet function under such-and-such circumstances." When other research groups study different kinds of wounds or inflammatory responses, the functions of the platelets are seen to diversify, depending on the situation.

Clearly, a specific cell type or molecule cannot do everything; it has a limited range of possibilities, but this range is fluid and not predetermined. This is what the research shows for virtually every cell type and molecule in the body. Since, however, cell and molecular biologists are so specialized today and each research group typically focuses on one particular molecule in one type of organism from one limited perspective, the fluidity of the processes becomes apparent only when scientists step back from their own work and review the broader research in their field.*

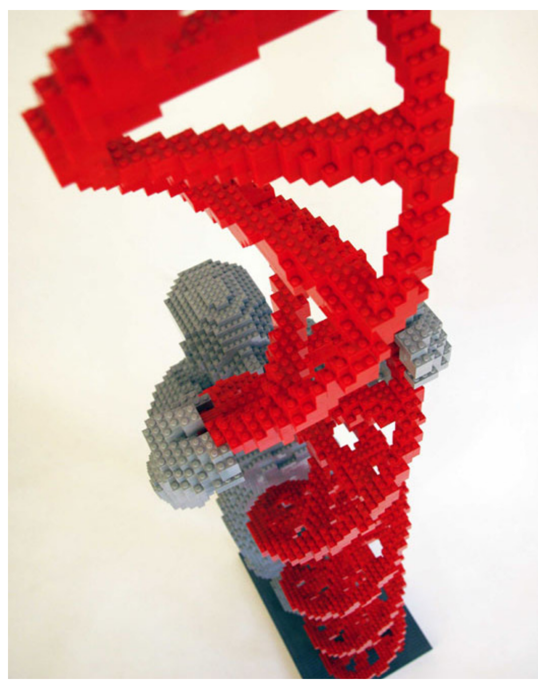
There is an important implication of this research: there are no specific or fixed pathways, and there is no "mechanism" (Talbott 2014). You simply cannot say that cell type X has function Y or that molecule S has mechanism of action T. What biologists hold in mind as determinate pathways are in fact specific realizations of the adaptive, flexible potential of the organism as it manifests in a particular cellular and molecular context. The reality of the mechanism is that it is the mental framework through which the phenomena are viewed; it is not something physically "in" the organism. To limit ourselves to investigations that look for proximal causal relations ("this molecule elicits that response") means to work within a narrow set of highly controlled conditions. We de-contextualize. That is fine, but we should not then forget what it is that we have done to achieve our results. The clarity gained comes at the cost of a loss of fuller reality, which only begins to show itself when we put our findings back into relation to the results of other experiments and we drop the mechanistic framework. What is determinative for one experiment is not determinative in biological reality.

Synthetic Biology

When we turn to synthetic biology, we come up against a very different way of thinking. This may in part reflect the fact that synthetic biologists often have engineering backgrounds, hold patents, and are involved in bioengineering start-up companies, so that they have a financial interest in their efforts coming to fruition.

How, then, do they tend to view living organisms and the task of synthetic biology? James Collins, a leading practitioner and proponent of synthetic biology, studied physics as an undergraduate, holds a PhD in medical engineering, and currently works at Boston University and Harvard. He writes:

> With a box of Lego[s], you can create a whole range of different structures. Snap together pieces of various colours, shapes and sizes to create a multitude of structures — a house, a boat, a tower—with different functions. In the world of biology, a growing group of scientists is thinking about parts of cells in much the same way. Engineers are using genes and proteins as building blocks to create new kinds of cells and new functions for cells. (Collins 2012)



"Building Bricks of Life," by Nathan Sawaya.
Image courtesy of brickartist.com.

* If biologists were to study and take to heart Goethe's seminal little essay "The Experiment as Mediator of Subject and Object"—written in 1792—they would realize the crucial importance of varying experimental conditions in order to gain a realistic picture of a given phenomenon. See: natureinstitute.org/pub/ic/ic24/ic24_goethe.pdf.

In the minds of synthetic biologists, organisms *are* machines, a point Drew Endy, professor of bioengineering at Stanford, makes in stark terms:

> For engineers, biology is a technology … To an engineer, biological systems are replicating machines that make mistakes during the replication process (that is, biological systems are reproducing machines). (Endy 2005)

And these machines can be improved:

> Synthetic biology is bringing together engineers and biologists to design and build novel biomolecular components, networks and pathways, and to use these constructs to rewire and reprogram organisms. (Khalil & Collins 2010)

The "biological machine" is often compared to a computer, here by Craig Venter, who gained fame as the leader of one of the two groups that first sequenced the human genome:

> The genome can be thought of as the software that encodes the cell's instructions, and the cellular machinery as the hardware that interprets and runs the software. Advances in DNA technology have made it possible for scientists to act as biological "software engineers," programming new biological "operating systems" into cells. (Gibson & Venter 2014)

With the notion of the precisely functioning mechanism as their idol, synthetic biologists look down on traditional genetic engineering: It is an "expensive, unreliable and *ad hoc*" technology (Endy 2005) that "generally requires many years of work and trial-and-error experiments to implement" (Arkin 2008). Synthetic biology wants to be more precise and achieve more predictable and controllable results through the application of strict engineering standards:

> Standards underlie most aspects of the modern world. Railroad gauges, screw threads, internet addresses, 'rebar' for reinforcing concrete, gasoline formulations, units of measure, and so on. In the science of biology, a number of useful standards have already arisen around the 'central dogma' that defines the core operations of most natural biological systems...." (Endy 2005)

The "central dogma" Endy refers to is the now outmoded 1960s hypothesis that all the information needed to form an organism is contained in DNA, and that this information is transferred only in one direction: from DNA to RNA to the proteins (enzymes) that in the end are responsible for building up and maintaining the organism. This idea gave DNA (genes) the central position in the "operating system" of the organism. On the assumption that a gene as a particular sequence of DNA determines the structure and function of a particular protein, you can easily conjure up the notion that the organism is built up out of discrete parts—the thousands of genes in DNA. DNA is viewed as a kind of biological code, as Collins views it:

> The genetic code is like any other language: to be able to write it, you have to learn how to read it and understand it. ... Our DNA was once an uncracked code as well, but over the past century, scientists have slowly learned how to read the genetic code that every living cell contains. They have figured out which genes determine which characteristics of cells and organisms, and how changes to genes can alter these characteristics. (Collins 2012)

It should, on this view, be possible to know these parts, to construct new ones for human aims, and to know exactly what these synthetic parts will do in an organism. That is one of the main goals of synthetic biology.

To achieve their aims, synthetic biologists want to construct "standardized biological parts" that can be put together to make "devices" that, when assembled together, would make a "system" (Endy 2005). "We define a biological part to be a natural nucleic acid sequence that encodes a definable biological function and a standard biological part to be a biological part that has been refined in order to conform to one or more defined technical standards" (Shetty et al. 2008). Such standard biological parts are often called BioBricks and they represent "sequences of DNA with specific function that can be combined together to implement more complex functions" (http://syntheticbiology.org/BioBricks.html). There is a public online registry of thousands of such parts (http://parts.igem.org/).

Synthetic biologists speculate that their technologies will help solve many pressing (and imagined) problems:

> What can synthetic biology do for us? How can moving genes around cells, creating biological circuits, and writing new genetic programs change the world? Many of the major global problems, such as famine, disease and energy shortages, have potential solutions in the world of engineered cells.... If scientists can build genes from scratch, they can create organisms with new traits. They can create bacteria that can clean up oil spills, rice with genes that keep the plant infection-free, or cells that can churn out new materials.... What if we could engineer humans with sonar, like that used by bats, to help us navigate in the dark? What if we had genes that enabled us to get energy from sunlight, like plants do? (Collins 2012)

> Synthetic biology is bringing together engineers and biologists to design and build novel biomolecular components, networks and pathways, and to use these constructs to rewire and reprogram organisms. These re-engineered organisms will change our lives in the coming years, leading to cheaper drugs, "green" means to fuel our cars, and targeted therapies to attack "superbugs" and diseases such as cancer. The *de novo* engineering of genetic circuits, biological modules, and synthetic pathways is beginning to address these critical problems and is being used in related practical applications. (Khalil & Collins, 2010; article's abstract)

Clearly, there is a good deal of self-promotion and hype in these statements. Every new technical innovation will, in the eyes of its inventors and promoters, help "solve" significant world problems. Whether it will actually end up doing so or not, or cause new problems that the next ingenious invention will have to solve, remains a question. What in any case is clear is that synthetic biologists pursue a mission—"redesigning," "reprogramming," "rewiring" life and, in the end, creating artificial life. This mission is driven by the image of the organism as a machine-like entity—a notion that permeates all their language. They aim to make living beings into the machines they imagine. They believe that existing life forms are imperfect and mistake-ridden and warrant improvement.

The Gulf Between Language and Facts

The term "synthetic biology" has caught on in the past decade. While it is relatively easy to formulate the engineering conceptual framework and the theoretical goals, it is another matter to discern whether research that runs under the name synthetic biology actually follows its strict engineering principles (Porcar & Peretó 2012).

For example, a new malaria drug, semi-synthetic artemisinin, is viewed as a product of synthetic biology (Peplow 2013). It is a drug that was developed with genetic engineering techniques, chemical synthesis, and also synthetic versions of DNA using synthetic biology principles and techniques (Paddon & Keasling 2014). However, as Porcar & Peretó (2012) point out, all the steps taken to produce this product hardly satisfy synthetic biology's claim of "predictability, lack of noise, orthogonality [i.e. independent functioning of the parts] and standardization." Nonetheless, in their review article, Paddon and Keasling, co-creators of semi-synthetic artemisinin, resort to engineering "synbio speak." For example, they use the term "chassis organism" when they refer to the host organism employed in the development of the drug. As the chassis of a car serves as the framework on which all the parts are mounted, so the host organism serves as structure upon which the biological parts are mounted.

To take another example, Craig Venter and his colleagues published an article in 2010 called "Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome" (Gibson et al. 2010). The article drew widespread attention, in part because people feared that the Venter team had created an artificial form of life. The team does not say they did. But they do say more than what their results—considered in a dry and not hyped-up fashion—warrant. What they did, briefly, was to chemically synthesize a genome, based on the known genome DNA sequence of the bacterium *Mycoplasma mycoides.* The synthetic genome closely resembled—except for additions such as "watermark" sequences for identification purposes—the bacterial genome; it was, in effect, an edited copy of it. The synthetic genome was then inserted into the cell of a different bacterium—*Mycoplasma capricolum*—and the resulting "hybrid" with the synthetic DNA was able to reproduce.

This was a remarkable technical accomplishment. But were Venter and colleagues the creators of a "bacterial cell" or, as they state in their article, a "synthetic cell"? No. They inserted a synthetic genome into a living cell that provided the context needed for the genome to do anything at all. Clearly, they were overstating their case, and it is disconcerting that the editors of *Science* paid no attention to the misleading claim. Commenting on the research, Mark Bedau—philosopher and editor of the journal, *Artificial Life*—more accurately describes the outcome as a "normal bacterium with a prosthetic genome" (Bedau et al. 2010).

The discrepancy between language and actual facts is of real concern. First, the language suggests that organisms are in fact the mechanistic assemblies (think again of the expression "chassis" for a host organism) that synthetic biologists treat them as. Second, the organisms and experiments are described in an engineering style, so that there appears to be more rigorous engineering at work than is actually the case. Third, the results are over-interpreted and framed to favorably fit the mechanistic mission. A kind of hubris takes root in the mind of synthetic biologists who boldly assert that they hold the key to improving organisms.

Living Beings Do Not Consist of "Independent Parts"

It is an important premise of synthetic biology that a standard part (a gene, for example) defines a clearly circumscribed function so that one could construct a device or

The tadpoles of the desert spadefoot toad (which is actually a frog; *Spea multiplicatus*) develop in small ephemeral ponds in the southwestern U. S. and Mexico. Depending on what they feed on, they develop in drastically different ways (Pfennig 1992; Ledón-Rettig and Pfennig 2011).

When they hatch, all tadpoles have the same basic morphology, but if they begin to feed on shrimp and continue to have shrimp as their main food, they develop rapidly, grow large in size, have large jaw muscles, notched and serrated mouthparts, and a short loosely coiled intestine (right in photo). In contrast, their siblings in the same pond (left in photo) may feed on dead organic matter (detritus) and microorganisms. These siblings develop much more slowly, are smaller, and have small jaw muscles, smooth mouthparts, and long coiled intestines.

Other environmental and maternal influences can affect the development of the carnivorous morph, as it is called, and, remarkably, the carnivorous tadpoles can transform back into the detritus-feeding morph if their food is altered. So the specific way these animals form and live depends largely on the active relation they establish with the environment, which in turn influences the formation and growth of their organs and body.

This is anything but machine-like behavior. Synthetic biologists may want to reflect on such realities of biological life when they imagine—and misconstrue—organisms as machines.

system with a predictable outcome. The parts should not do something that has not been foreordained. For this reason, "for engineering purposes, parts are most suitable when they contribute independently to the whole. This 'independence property' allows one to predict the behaviour of an assembly" (Benner & Sismour 2005). Synthetic biologists often speak of independent modules, and the mutual independence of parts is also called "orthogonality."

The question is, do such independent parts exist in real-life organisms? We saw at the beginning of this article in discussing platelets and connective tissue growth factor that this is certainly not the case. Describing what is known about the platelet-derived growth factor (PDGF), professor of genetics and developmental biology, Bruce Mayer, and his colleagues come to the conclusion that "the activated receptor looks less like a machine and more like a ... probability cloud of an almost infinite number of possible states, each of which may differ in its biological activity" (Mayer et al. 2009).

But what about the sequences of DNA we call genes? The same picture is emerging for DNA as it is for all other substances in the body: all its activity is highly context dependent. Geneticists Emmanouil Dermitzakis and Andrew Clark (2009) remark that "we tend to talk about pathways and processes as if they are discrete compartments of biology. But genes and their products contribute to a network of interactions that differ radically among tissues." Such "discrete compartments"—the ideal "parts" of synthetic biologists—do not in fact exist in organisms.

The scientific literature on the biology of organisms is full of such examples. Based on his reviews of current research in molecular biology, Steve Talbott concludes:

> One reason we cannot explain the organism through the relations between parts, is that those parts tend not to remain the same parts from moment to moment. For example, as most molecular biologists now acknowledge, there is no fixed, easily definable thing we can call a *gene*. Whatever we do designate a gene is so thoroughly bound up with cellular processes as a whole that its identity and function depend on whatever else is happening. The larger context determines what constitutes a significant part, and in what sense, at any particular moment. Where, then, is any sort of definable mechanism? (Talbott 2012; see also Talbott 2014)

When biologists begin reckoning with the dynamic and contextual nature of biological processes, the concept of the gene loses any clear-cut demarcation:

> Genes might be redefined as fuzzy transcription clusters with multiple products. (Mattick et al. 2010)

> [A gene is] a statistical model to help interpret and provide concise summarization to potentially noisy experimental data. (Gerstein 2007)

The gene has turned out to be a highly abstract and fuzzy concept precisely because the organism is not a mechanism.

And genes are not what make things happen in the organism. Writing in the journal *Science and Education* with the aim to bring science educators up-to-date about the current concept of genes and DNA, Charbel El-Hani and his colleagues emphasize that "it is not DNA that does things to the cell; rather, it is the cell that does things with DNA. This is, indeed, one of the major conclusions we can take from developments in the debates around the gene concept in the last three decades..." (Meyer et al. 2013). Because of this context dependency, genes should be, in their words, "conceived as emerging as processes at the level of the systems through which DNA sequences are interpreted, involving both the cellular and the supracellular environment. Thus, genes are not found in DNA itself, but built by the cell at a higher systemic level."

The reality of "parts" within organisms is that they are not definable independent entities but rather interconnected and dynamic processes or potentials that respond and change in relation to changing situations. This is hardly the notion of a "standard biological part." At least to a degree, this is recognized by some synthetic biologists, such as Timothy Gardner and Kristy Hawkins, who write: "natural biological parts are often not modular. Small changes from part to part, or the molecular context in which the part is situated, produce oft-times significant variation in the functional behaviors" (Gardner & Hawkins 2013).

The Failure of Synthetic Biology Systems

Given the fact that the synthetic biology framework does not conform with organismic reality, it is not surprising that synthetic biology design experiments have often failed to work. This has not, of course, gone unnoticed by the synthetic biology community. A review article by synthetic biologists Stefano Cardinale and Adam Arkin of the Lawrence Berkeley National Laboratory tries to identify the "causes of failure of synthetic biology systems" since all too often, as they state, "molecular and genetic devices inexplicably fail to function as designed when tested in vivo" (Cardinale & Arkin 2012).

Spanish systems and synthetic biologist Victor de Lorenzo (2014) writes that "synthetic biologists have created a large number of genetic circuits in which transcription factors and promoters are rationally re-connected following a man-made blueprint aimed at programming new-to-nature properties" (see also Khalil & Collins, 2010, for many examples). De Lorenzo points out that "it is now common knowledge that such devices operate for a limited period of time, after which they often succumb to noise and mutations."

For instance, part of the genome of the T7 bacteriophage—a virus that infects bacteria—was reconfigured ("refactored") by scientists (Chan et al. 2005). The modified phage was able to infect bacteria—it was functional in this sense and is cited as an early example of successful synthetic biology. However, "its subsequent evolution in vivo whilst progressing towards recovering the fitness level of the wildtype phage erased 40% of the manmade modifications. In contrast, naturally occurring regulatory circuits are quite robust, and maintain their performance across time and space" (de Lorenzo 2014).

Part of the "problem" of real organisms is that they live in variable environments and can respond meaningfully and in a variety of unpredictable ways to those variations. So one strategy of synthetic biology is to create highly uniform and stable conditions in the environment so that the organism with its new synthetic parts is not subjected to the myriad perturbations in real-world life. Therefore, writes biotechnologist and bioengineer Martin Fussenegger in a sober assessment, "should a species with a programmed synthetic genome one day become useful, it would probably be contained in specific production environments" (Bedau et al. 2014). He's thinking of micro-organisms carrying out specific processes or producing specific products in highly controlled industrial conditions.

Making Machine-Like Organisms?

But the goal of synthetic biology is not only to control the environment, but also to control internal functions of organisms. Therefore the contextual, situation-dependent activity of the organism at all levels presents a major challenge; it is a "barrier to predictability in design" (Cardinale & Arkin 2012).

In a moment of circumspection synthetic biologists Bashor and Collins admit that "engineered biological circuits rarely work as designed. In most cases, the performance of their molecular parts is highly dependent on cellular and sequence context and varies greatly from one system to the next" (Bashor & Collins 2012). What is their response to this challenge? Unfortunately, they do not rethink their approach in light of the reality of organisms. No, the unwieldy nature of organisms needs to be overcome. "Synthetic biology urgently requires strategies to limit such context-dependence."

We should let this sentence sink in. Limiting context dependence means making an organism less of an organism and more machine-like. It means limiting the spontaneity, unpredictability, and flexible responsiveness that are integral to life. So if synthetic biology actually follows its own principles and strives, in its view, to "improve" plants, animals, and human beings, then it will "succeed" to the degree that it limits or eliminates essential characteristics of life.

Given the degree of technical sophistication, zeal, intelligence, and funding that supports synthetic biology, I have little doubt that, left to its own devices, it will forcefully pursue this goal. And since living beings are above all else adaptable, I can imagine that synthetic biologists will find ways to make them accept and adapt to their machine-like assemblies. But I'm even more certain that along the way much will go wrong and there will be many unintended consequences—for the organisms themselves and for the larger environment as well.

What is particularly disturbing about synthetic biology is that we know today that organisms are not machine-like assemblies. So why would we want to implement an inadequate framework? Is the deeper motivation that the engineering mind simply wants to follow its fascination with absolute control and predictability? Shouldn't we consider more thoughtfully what it means when human beings engage in the activity of making other living beings and perhaps ourselves into less-than-living "systems"? Can we do that responsibly? What boundaries can or should be set? Who can set such boundaries?

Whether and how these questions are addressed should not be left up to the community of synthetic biologists and its funders, given their mission-driven zeal and power. These are urgent questions that warrant attention and consideration by a larger community of concerned lay people, environmentalists, scientists who are not proponents of synthetic biology, policy makers, and, yes, synthetic biologists.

Of course, who of us comprehends life and knows all we should know before we act? But there are two different kinds of ignorance. We can study the phenomena of life and realize life's intricacies, its remarkable plasticity, its context-sensitivity, its aliveness. In the process of gaining this knowledge we begin to realize how little we know. This is wise Socratic ignorance—knowing you don't know. It is a kind of ignorance that encourages circumspection and caution in action. But there is also the very different ignorance that Herman Wouk captures when he writes about someone being "too clever to be wise." This ignorance is blinded by its own intelligence, ignores what it does not want to see, and strives to bend reality to fit its mission: man manipulating life in service of the machine idol. This ignorance fosters hubris that tends—because it thinks it knows best—to run roughshod over the intricacies of life.

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(*continued from p. 8*)

life unreservedly to mindless mechanism—is now posing its own severe challenges. In this era of Big Data, the message from every side concerns previously unimagined complexity, incessant cross-talk and intertwining pathways, wildly unexpected genomic performances, dynamic conformational changes involving proteins and their cooperative or antagonistic binding partners, pervasive multifunctionality, intricately directed behavior somehow arising from the interaction of countless players in interpenetrating networks, and opposite effects by the same molecules in slightly different contexts. The picture at the molecular level begins to look as lively and organic—and thoughtful—as life itself.

The hope — epitomized cleanly and algorithmically by "DNA makes RNA and RNA makes protein"—had been that, at the molecular level, we would find the unambiguous relationships, principles, and laws that explain all the complexities of the organism as a whole. Yet now the advice we hear is to step back and see larger wholes—functional modules, networks, and systems—in order to explain or make sense of isolated molecular dynamics. It is when we gain a little distance from the immediate causal interaction between a few entities and begin to survey *narrative* threads in a larger context and over time, that we begin to discern what seems (yes, even at the molecular scale) to be the *intentional* significance of what is going on.

There are, of course, biological disciplines where the challenge of the mindlike is taken up with great seriousness. Cognitive science—bringing together (at least) psychology, neuroscience, linguistics, artificial intelligence, philosophy, and anthropology—is a field upon which advocates of remarkably diverse points of view often joust in free and bracing intellectual combat. One need only browse the *Journal of Consciousness Studies* to witness the creative ferment now attracting so many researchers.

How many molecular biologists today would feel such freedom—the kind of freedom Richard Conn Henry knew within the physics community? I mean, for example, the freedom to wonder aloud whether intention and agency, so difficult to banish from biological description, might be at least as fundamental to biological understanding as the local causal interactions we are so expert at fingering.

Why should the consideration of mindfulness, which presents such a vivid and stimulating conundrum to researchers in a number of respectable sciences, be absent from what are usually considered the core disciplines of biology? Perhaps most molecular, cellular, and evolutionary biologists are prepared to claim—despite their own heavy reliance upon a mentalese dialect, and despite all those kindred disciplines actively wrestling with the problem of mind—that the conundrum merely reflects an unusually persistent confusion that ought to be clarified once for all and dispensed with.

But if it's this simple, then why a silence that has all the appearance of being taboo-enforced? *Let the conversation begin!*

Note

1. Send your proposal to stevet@natureinstitute.org. I may not be able to respond personally, but you can be sure I will be taking up this matter in the future.

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