Science and Crafts

Roald Hoffmann

I came to Penland to write. The crafts were dear to me; first textiles, especially bobbin lace, which my wife made and collected, and taught me to look at. Then the Japanese ceramics to which Kenichi Fukui and Fred Baekeland introduced me, followed by the protochemistry of dyeing with indigo from snail and plant sources, to me still the ideal bridge between science and culture. The tribute is to be seen around my house—my children's inheritance consumed as much by crafts as "high" art.

So it was easy to accept an invitation to come to Penland and write. Who knew what would come? I wanted to write poems, perhaps an essay. For the poems I've needed nature—not so much to write about as to shake me loose from the everyday worries of the daily life I had in Ithaca. Nature was a path to concentration; I expected to find a different nature in the foothills of the Blue Ridge Mountains. I would watch the crafts process. Maybe someone would even let me try something. Or ask me to tell them of the chemistry of their craft. I, in turn, would craft my poems out of the green hills.

But this is not what happened. Here's what happened: I walk into Billie Ruth Sudduth's basketry class, and there's the whole group dyeing their canes—steaming pots of synthetic dye. I ask someone what they are doing, and she says, "Well, I'm getting ready for the upsetting," and then seeing the puzzled look on my face, patiently explains this old, wonderfully direct basketry term for bending the canes forming the base of a basket over themselves, so that they stand up.

I walk uphill to the iron shop, clearly more of a macho place, watch an intense young man, lawyer become sculptor as it turns out, hammer out a hand on a swage block. Ben tells me that it's possible to burn away the carbon in the steel, and the iron would "burn" too—oxidize, in too hot a flame.

In a studio downhill, a young student carefully carves out the wax sprues (yes, I have to be told what these are—and I thought science was full of jargon!) that will eventually help him form silver leaves. His instructor, thinking I might be the useful sort of chemist, asks me about gases emitted when the "investment" hardens. Alas, I'm a theoretician, as impractical as they come within this profession.

There is no time to write, poetry suffers. The only nature I encounter are the ubiquitous fireflies as I walk back to my cottage late at night. I think of their wonderful luciferase chemistry, their rhythms and deceits—one carnivorous firefly species imitating another's flashing rhythm to lure a male to death.

My heart is open. I am in thrall to these intent older and younger people, and the transformations they perform. I am not even discouraged that my own attempts at pots, under the tutelage of a great teacher, Paula Winokur, or my try at blowing glass, or forging iron, fall short. I need practice. And I reflect on the kinship I have, as a scientist (and writer, too), with the creators of crafts. The magic of Penland opens people to each other and their hands' work. But there are deeper ties.

Natural/Unnatural

In the context of environmentalist and ecological disputes, scientists and technologists are often branded as the makers of the unnatural. Aware of the shades of meaning, progressively negative, which accompany the words crafted, man- or woman-made, artificial, synthetic, unnatural, I use unnatural as a provocative extreme. Because that's how people see it. Sure, you could say everything people do is natural because they/we, the makers, are. And we certainly deconstruct the natural/unnatural distinction every moment of our creative, transformative lives. Taking the natural, changing it. Making naturalistic shapes out of the most synthetic of materials. But I think it makes sense to distinguish the actions of human beings from those of the rest of nature, if we are to have a sensible debate on the environment.

My personal way to overcome this facile categorization into natural/unnatural is to ask people to think what's natural about a John Donne poem, Orson Welles at his most evil in *The Third Man,* a Bach cantata, a desegregation law. These are acts of human creation, they enliven (and may hurt—a romantic affectation of artists is that all art is inherently positive). We have been put on earth to create. And as human

Photo: Ann Hawthorne

beings, the act of creation of molecules or poems must be coupled with an ethical assessment—will this hurt, will this heal?

At Penland, everyone, absolutely everyone, was into making the artifactual, into transforming, changing, modifying nature. From the wonderful sculpture of a ballerina's tutu made from birch bark, to the shibori dyed cloth, to the shaved stakes worked into a basket, people were taking one thing (natural or synthetic) and transforming it into another. Yes, they did care about natural or synthetic dyes—maybe they'd use, for class purposes, synthetic dyes to color cloth or basket cane. At home they'd think again—some would stick with natural dyes; most I suspect would not.

The natural/synthetic story is fascinating in detail, and in the way it has provided an ethical dimension for crafts. People who make things for use (or beauty; could we live without it?) will go with any technical advance. No commercial fisherman will return to cotton nets after using nylon. Within three years of aniline dyes coming on the market in Germany, they were used in Persian villages, to the detriment of the rugs, initially—some of the first dyes were corrosive to the wool. Navajo weavers unraveled Spanish red cloth, bayeta, to reweave it into their blankets.

Bright color has a way into the soul. And since synthetic dyes often are more intense in hue than natural ones, they have always tempted the craftsperson. I like the idea that the question of what dye to use now has an ethical dimension for the craftsperson. And, to complicate matters, I like also that we have an inversion of the old class/color correlation—no longer are the rich more colorful.

In the company of craftspeople, I did not need my prefatory plea to recognize that we are all in the business of transformation. And we could move on—perhaps to the associated ethics, perhaps to the aesthetics.

Photo: Evon Streetman

Measuring a vessel

Chemistry

Not only were the craftspeople at Penland transforming the natural, but they were just plain doing a lot of chemistry. I've mentioned the dyes for textiles and baskets. In the magic of clay fired to a ceramic there was chemistry, also in the colors of the glazes. Higher up the hill was the land of perfervid metallurgy—people were not winning metals from their ores, but they were pouring bronze, burning out plastic or wax, annealing, tempering, etching, grinding, welding. I loved the sounds of the work. There were chemicals in the print shop, and the developer and hypo in photography.

There was concern about the health effects and safety of these processes—as there should be. The concern was amplified by the fact that people sometimes didn't know what they were working with; the ingredients were not specified (as little descriptive as "red earth" or "stabilizer"). Some people used the hazardous material data sheets provided by the school, others did not. All were torn by the tension of wanting to use materials that expanded the range of what they could do, and not being sure of the biological effects of the new materials. Chemistry is the art, craft, business, and now science of substances and their transformation. It was fun to see so many cryptochemists! Good, practical chemistry was being done left and right. In the usual way people have of thinking they are insufficient, and not having gone through a chemical apprenticeship, crafters were hesitant, and thus a little afraid of me, a professional chemist. Little did they know that I, a theoretical chemist, was much more of a klutz in practical chemistry than they were!

The craftspeople I met also weren't quite aware of how much they, in fact, were like professional chemists. What I mean here is that both scientists and crafters alternate doing things carefully (measuring out that bevel, controlling the kiln temperature), and tinkering, trying things, trying them again to get a process to work.

Sanding concrete

Chemists also pursue matter in all its rich variety on the microscopic scale—they think of chemistry as being the transformation of persistent groupings of atoms we call molecules. What happens downscale, to the molecules and their constituent atoms, determines, as one moves upscale, what form macroscopic substances take on and how they transform. Their colors, crystalline shapes, their biological effects, their chemical reactions—all these have a molecular basis.

The creative people I met were moving on the macroscopic plane. Would it help them to know more about the small structures inside?

How Much Does One Need to Know?

Not much. A lot. Just enough to create. I am speaking of the knowledge of the materials we work with, both as they "rest," and as we transform them. Is it important to know that steel is an alloy of iron and carbon, and that the carbon is there in several ways—part a solid solution in the interstices of metallic iron, part in discrete Fe_3C and Fe_5C_2 compounds? Should one care that the chemical structure of indigo is the one shown here, and that to have it bind better to wool and linen one has to "reduce" the molecule to a colorless form, which, once absorbed into the biopolymers, is oxidized back to a molecule colored "like unto the sea and the sea is like unto the sky and the sky is like unto the sapphire, and the sapphire is like unto the Throne of Glory" as Rabbi Meir said of the wondrous dye?

The art is wonderful, the overall change possessed of sufficient mystery to make the spirit soar when the blue of the dye reappears as the oxygen of the air hits the wool. Need we care about what happens on the molecular level?

Curiously, the question "Should I know?" or rather "Should I learn deeper?" is there in science as well. The special context there is reductionism—a world-view (unrealistic and unworkable in my opinion) that science bought into early on. By reductionism I mean the description of a hierarchy of sciences, and a definition of understanding in terms of a reduction from one science to another. So behavior is to be understood in terms of biology, biology is to be understood in terms of chemistry, chemistry in terms of physics. Given the premium on understanding, in this hierarchy there is no question that there is more value in going deeper. And deeper is defined in terms of reduction.

Actually, this kind of reasoning is often used as a rhetorical avoidance strategy for those unwilling to broach the real world—how matter might behave upscale.

In that real world, now of the practicing chemist, things operate very much as they do for the craftsperson. Chemists analyze, to be sure. But much of their activity is creative, the uniquely chemical matter of synthesis. A few hundred thousand new compounds are made each year. Why? For all kinds of reasons. For example, to make an anti-tumor agent, isolated from the bark of a yew tree in the lab, so one wouldn't kill yew trees by stripping their bark. Thus for a specific use. Also to "sell" these molecules. And for fun. There's no utility in a molecule shaped like an icosahedron, made all out of boron and hydrogen. When carbon wants to have four bonds going out toward the vertices of a tetrahedron, what would it take to induce those bonds to align themselves in the four directions of a square? The syntheses of chemists here are driven by beauty. And, incidentally, not only the facile beauty of Platonic polyhedra, but that beauty much harder to learn to love, in crafts or science: that of rococo intricacy.

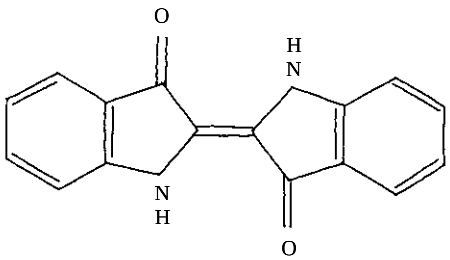
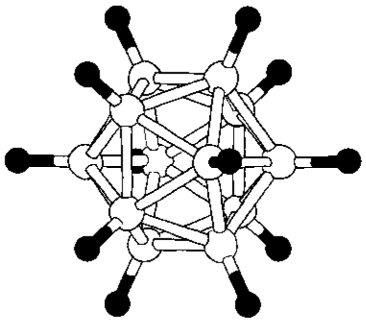


Diagram of an indigo molecule

Photo: Ann Hawthorne

The mix of utility and beauty as motivation pervades science, as it does the crafts. And, in both fields, utility and beauty may be uneasy partners.

In making a molecule, the synthetic chemist often uses processes that he or she does not fully understand (to a reductionist's satisfaction). So there's a catalyst, a metal powder primed by another chemical, and that catalyst adds two hydrogens to a molecule just there, and not here. And while we don't know exactly how it does that, it does it so efficiently and reproducibly. The practical chemist often says, "I'll take that, let someone else find out how it works." My métier is actually calculating how it does work, on the atomic level.



Model of an icosahedral $B_{12}H_{12}^{2-}$ molecule

Here's a practical argument for trying to understand, at every level, in crafts or science: The synthesis, or carving a pattern of grooves into iron, is going great. But one day the catalyst fails to do its expected magic. And the next batch of steel just fails to give those temper colors. What does one do? Throws away that catalyst, that block of steel. Tries another. And then that fails, too. There must be a reason, which will not be revealed by prayer or anger—there is an argument here for trying to comprehend, at least piecewise, enough to fix something when it goes wrong. As it will.

But I think the primary argument for understanding is ultimately psychological and aesthetic, rather than practical. Potter Paulus Berensohn writes:

> The molecules of clay are flat and thin. When they are wet they become sticky with plasticity and hold together as in a chain. A connecting chain. I like picturing that connection in my head.
>
> I am making my connection with clay. Clay turns me on and in. It seems clearer and clearer that I was drawn to clay by its plasticity. For it is plasticity that I seek in my life. To be able to move into new and deeper forms as well as make them. Making the connection and being plastic.

Knowing that in the fibers that will form paper is cellulose, gleaning from the arrangement of atoms in that molecule its kinship to rayon and to sugar or starch—that knowledge may be of little direct use to the craftsperson. But I think it makes all of us feel better—for understanding pleasures the mind.

Knowledge not only satisfies, but it also bolsters the mind when things don't work—when the flux pulls away from the metal, or the paper cracks. The intuition to try something else comes from knowledge subconsciously assimilated. One can go on, there are reserves of intuition to take a new tack. Knowledge also counters alienation—that of art from science, that of us from our materials and tools. These molecules are similar, they are different. They share some things, differ elsewhere. We see the world as connected. As making at least a little sense. And go on to make the next thing, as we are driven to do.

Keeping cast glass hot

Photo: Dana Moore

With or Against

You must go with the material, of course. The clay needs to be dried before it is fired, the glass and metal annealed. I watched Greg Fidler at Penland shape an glass bulb he had blown on a rounded wood form, flatten it a little, extend the thick neck separating it from another, connected bulb, soften the neck, and wait patiently for the moment when he would swing the blowpipe with the glass attached in a near circle. The neck stretched and the round bulb bent over as the steady swing was completed, in that moment nestling gently into the space the other flattened yet slightly curved shape made for it. There was suspense in that swing. And Greg knew when he could do it.

In his New York studio I watched a master sculptor, Daniel Brush, re-create Etruscan granulation, a way of attaching thousands of tiny gold spheres to a flat or curved gold sheet. The spheres loosely glued in place, he sprinkled the surface of the spheres with a copper salt, and heated it. As the object approached the softening temperature of gold, Daniel had all of about one second in which the alloyed copper metal formed on the sphere surfaces, melted, a tad before the gold, ran down the outer surface of the sphere, and formed a perfect weld at the juncture with the flat. Had he stopped heating a second earlier, there would be no bond. A second later the spheres would just melt.

"Going with" comes from observation, while working. Which builds into competence and is ultimately transformed into intuition, body, and mind intertwined.

But the will must be there to make out of the natural both the useful and the transcendent. I think of Antonio Gaudi's dragon in the gate to the Finca Güell in Barcelona. What iron ever wanted to be such a fierce segment of our imagination? I think of Egin Quirim and Cosmos Damian Asam, concocting a stucco angel on a fat cloud, just soaring out of a wall toward us in their Bavarian rococo church.

In science, as in craft, the master just knows what filter will effect the separation, intuits the flux to be used to make a solid state reaction run. And the apprentice learns. Intuition begins in trial and error, respecting the richness of matter and its changes. Homage is paid to chance, serendipity can be courted when invention stagnates.

But ultimately one tries to make matter do what it had not done before. This, incidentally, is what distinguishes chemistry from other sciences, and puts it close both to engineering and the arts. Maybe that's where crafts are, too! We

Metalsmith's studio

chemists make new molecules, a few hundred thousand of them every year. With the intention to do no harm, if not to heal. And yet some of them, like the chlorofluorocarbons that damage the ozone layer, hurt. But then creation has always been a risky business, and I'm not just talking about procreation. In the *Popol Vuh,* the book of the Quiché Maya of present day highland Guatemala, are told stories of several creations that went astray.

I saw a paper recently in which a German chemist reported the making of a line of six carbon atoms, bound to a line of three osmiums, each bearing several carbon monoxides. An unnatural assembly itself, it could be traced back to the naturally occurring element osmium, carbon from petroleum sources, and natural/synthetic (and poisonous) carbon monoxide. I saw that one line of atoms was tensed and curved, more than the other. Hard to know who to blame—carbon or osmium? One of my graduate students, Pradeep Gutta, said, "Hey, how about making a big circle out of it?" He had thought of the tension of an arc, of allowing it to play out that tension by completing a circle. Off he went to the computer, to build a model of the electron motions in that circular ribbon of osmium, carbon, and CO. Pradeep is most certainly going with what the molecule "wants" to do. And he is transforming it (on paper in our case, for we are theoreticians; but we have such great faith in our experimental colleagues—it will be done!) into something new and beautiful. And who knows, maybe useful.

Photos: Ann Hawthorne

A master smith

said: comply, but
contend—make

hard soft, hard
again, beat blade

and girder into
rabbit's ear and

morel. Love, oh
love for steel too,

is built sweet out
of strict desire,

for the you, that
is not you. You.

Like a Horse and Carriage

For one aspect of craft there is an easy scientific counterpart—it is the experience of experimental work, using tools. Take DNA. One had to be able to separate biomolecules, and build X-ray diffractometers, before the structure of DNA could be deduced theoretically by two young helixeers fifty years ago.

But what is art in science? Is it theory, viewed in the general sense as the building of frameworks of understanding? It can't just be theory. I think the analogue of art is the imaginative faculty, which makes scientists creative. It does not come to the fore in deductive thinking, or applications of that easy idol of science, Occam's razor. Art is in the formulation of far-out hypotheses, in seeing connections between the seemingly unconnected, in designing instruments and experiments.

Science, a European invention, is a system for gaining reliable knowledge by the interaction of curious yet fallible human beings, who are obliged to tell others what they have done. Science also mandates a continuous dipping back and forth between reality (gauged by our senses and instruments) and flights of theoretical fancy.

So the system of science enforces links between the art of hypotheses and the craft of the instruments. You just can't have one without the other—a theory not tested will not be accepted, and reports of experience without trying to understand it (without a theoretical framework) are unreadable. It sure looks like you can't have the art of science without its craftsmanship.

Another interesting intersection is around the idea of utility, a subject not without dispute in the crafts. When is a teapot not a teapot? Does it matter whether a shape sells? The crafts were always of commercial value, they were a profession. And there were middlemen, even way back then. Half the students at Penland when I was there were making a living, or trying to do so, from their crafts.

Utility at first sight poses a problem. For many thoughtful theories of art conclude that the concentration, intensity, and unity in an art object can only be appreciated if one is disinterested in its value, whether monetary or utilitarian. I hear snickering on how this applies to the objects consecrated in our temples of high art. That aside, and admitting the corruptive power of money and familial (or political) relationship, I think it is too harsh to deny the beauty/crafting personal bond between object and human that daily use creates. Of a teapot, or my Harris tweed jacket.

There is an interesting utility/knowledge for knowledge's sake (substitute "art" for "knowledge") tension underlying all of modern science. We need support—once it was called

Precision jewelry making

Sculpting clay

Photo: Ann Hawthorne

patronage. Yet we resent it when the government, the modern patron, tries to direct our work with a dollared carrot—come work on “star wars” and you’ll get support! At the same time we forget a little about the meliorative aspect, the desire to help people, to leave the world a little bit better place than it was before. In general, applied scientists don’t get much prestige in academia. And yet one out of two assistant professors in molecular biology and materials science is running after that new start-up company.

I look at a mask on my wall by Alaskan native Evans Apatiki—carved whalebone, polar bear fur around it. It evokes its animal construction, its ritual use. And the mask is as expressive and constructed as an Ernst Barlach sculpture; or as the synthesis of vitamin B12 by R.B. Woodward and Albert Eschemoser with ninety-nine friends—each step necessary, executed with improvisational aplomb, a thing of beauty.

Hands and Minds Combined

From time to time, we in chemistry are put under pressure to teach an introductory course without a laboratory. Couldn’t you just talk about the logic of chemistry; wouldn’t some molecular models and good stories suffice? At one such meeting, there rose to our defense a printmaker. He said, “There’s a difference between talking about lithographs and making one,” and sat down.

There is no question that the crafts are about hands and the senses, especially vision and touch. And sounds too—at Penland I loved the unexpected roar of the iron furnace, scissors snipping through paper, even the buzzsaw (at a distance). With a guiding mind, and yes, with tools and chemicals, a photograph is developed, printed, pasted into a book.

And science is about tools, and handwork too. Though the heroic figures of physics are by and large theoreticians (Fermi and Rutherford are the exceptions), the practice even of this quite mathematical science is largely experimental. The tools may be fancier, all those laser spectroscopes. But on the “optical bench” are carefully mounted mirrors, machined vacuum chambers, and yes, even now, blown glass containers—all designed and made artifacts.

For the crafts and for science, this—that both thinking and doing are engaged and cooperating—is our finest link. The world is disintegrated—separating mind and body. We cater to the mind through a novel or a Bach cello suite on a CD. And to the body through the long sanding of the walls before painting, or those Nautilus machines. Craft and science, both, integrate mind and body.

Could one imagine making a bracelet, linked silver triangles with an inlaid braid, without planning it out, making a mold for the triangles (all different), hammering in the decoration? The synthesis of a molecule shaped like a necklace—yes, there is such—begins with a plan. Which has to be changed a few times as one moves along, for things *do* go wrong. But the molecule is also a macroscopic substance, a solid, crystalline, each crystal the blue of aquamarines in a real necklace. And being something real and substantive, this necklace-shaped molecule must be made. It happens, in a wondrous ballet of all the glass vessels you can conjure up, the sequences of heating and stirring, of bubblings, filterings, stinky solutions, and mother liquors. It’s a long day’s night to make it, bracelet or molecule.

At the end, there’s craftsmanship, the proud, cunning work of human hands and mind, joined in the service of creation.

Working with craft materials really helps people to learn to think. It's a very strong force in cognition when you express ideas through elemental or primary materials. It's problem solving, but it's also problem inventing: thinking of things that need to be done.

Ceramist ***William Daley,*** *Penland Line,* Fall 1996

Part of the dilemma we're in right now is that we're trying to make people one-dimensional; you have to be a specialist, even in the arts. I would like to remove the limitations. For instance, chemistry is related to printmaking because you can't have inks without chemistry, and you can't have paper without some kind of chemical bonding. I'm trying to get the people I teach to think on that level, that it's all connected.

Printmaker and sculptor ***John T. Scott,***
Penland Line, Spring 1996