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# Turning Leaves

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# Leonardo's Holistic Science



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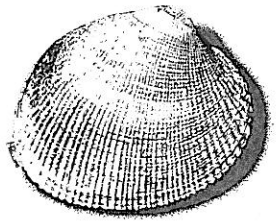

Leonardo da Vinci, the great master painter and genius of the Renaissance, has been the subject of hundreds of scholarly and popular books. However, there are surprisingly few books about Leonardo's science, even though he left voluminous notebooks full of detailed descriptions of his experiments, magnificent drawings, and long analyses of his findings. Moreover, most authors who have discussed Leonardo's scientific work have looked at it through Newtonian lenses. This has often prevented them from understanding its essential nature, which is that of a science of organic forms, a science of quality, one that is radically different from the mechanistic science of Galileo, Descartes, and Newton. [1]

**The empirical method**

In the 1460s, when the young Leonardo received his training as painter, sculptor, and engineer in Florence, the worldview of his contemporaries was still entangled in medieval thinking. Science in the modern sense, as a systematic empirical method for gaining knowledge about the natural world, did not exist. Knowledge about natural phenomena, some accurate and some inaccurate, had been handed down by Aristotle and other philosophers of antiquity, and was fused with Christian doctrine by the Scholastic theologians who presented it as the officially authorized creed and condemned scientific experiments as subversive, seeing any attack on Aristotle's science as an attack on the Church. Leonardo da Vinci broke with this tradition:

*First I shall do some experiments before I proceed farther, because my intention is to cite experience first and then with reasoning show why such experience is bound to operate in such a way. And this is the true rule by which those who speculate about the effects of nature must proceed.*[2]

One hundred years before Galileo and Bacon, Leonardo single-handedly developed a new empirical approach, involving the systematic observation of nature, reasoning, and mathematics — in other words, the main characteristics of what is known today as the scientific method. He fully realized that he was breaking new ground. He humbly called himself *omo sanza lettere* ("an unlettered man"), but with some irony and with pride in his new method, seeing himself as an "interpreter between nature and humans."

For forty years, Leonardo collected his thoughts and observations, descriptions of hundreds of experiments, drafts of letters, architectural and technological designs, and reminders to himself about future research and writing in his celebrated Notebooks. It is believed that the entire collection ran to 13,000 pages when Leonardo died without having sorted them, as he had intended. Over the subsequent centuries almost half of the original collection was lost, but over 6,000 pages have been preserved and translated from the original Italian. These manuscripts are now widely dispersed among libraries, museums, and private collections — some in large compilations known as *codices*, others as torn pages and isolated folios, and a few still as notebooks in their original bound forms of various sizes.[3]

**The science of painting**

Leonardo was gifted with exceptional powers of observation and visual memory.
He was able to draw the complex swirls of turbulent water or the swift movements of a bird with a precision that would not be reached again until the invention of serial photography. He was well aware of this extraordinary talent and considered the eye as his principal instrument, both as a painter and a scientist.

*The eye, which is said to be the window of the soul, is the principal means whereby*

*sensory awareness can most abundantly and magnificently contemplate the infinite works of nature.*[4]

Leonardo's approach to scientific knowledge was visual; it was the approach of a painter. "Painting," he declared, "embraces within itself all the forms of nature."[5] I believe that this statement is the key to understanding Leonardo's science. He asserts repeatedly that painting involves the study of natural forms, and he emphasizes the intimate connection between the artistic representation of those forms and the intellectual understanding of their intrinsic nature and underlying principles. For example, we read in a collection of his notes on painting, known as the "Treatise on Painting" (*Trattato della pittura*),

*[Painting] with philosophic and subtle speculation considers all the qualities of forms... Truly this is science, the legitimate daughter of nature, because painting is born of nature.*[6]

**The nature of life**

Painting, then, is both an art and a science for Leonardo — a science of natural forms, of qualities, quite different from the mechanistic science that would emerge two hundred years later. Leonardo's forms are living forms, continually shaped and transformed by underlying processes. Throughout his life he studied, drew, and painted the rocks and sediments of the Earth, shaped by water; the growth of plants, shaped by their metabolism; and the anatomy of the animal body in motion.

Nature as a whole was alive for Leonardo, and he saw the patterns and processes in the microcosm as being similar to those in the macrocosm. In particular, he frequently drew analogies between human anatomy and the structure of the Earth, as in the following beautiful passage:

*We may say that the Earth has a vital force of growth, and that its flesh is the soil; its bones are the successive strata of the rocks which form the mountains; its cartilage is the porous rock, its blood the veins of the waters. The lake of blood that lies around the heart is the ocean. Its breathing is the increase and decrease of the blood in the pulses, just as in the Earth it is the ebb and flow of the sea.* [7]

This analogy between microcosm and macrocosm goes back to Plato and was well known throughout the Middle Ages and the Renaissance. But Leonardo disentangled it from its original mythical context and treated it strictly as a scientific theory. Today we know that some of the analogies in this passage are flawed, and in fact Leonardo himself corrected some of them late in his life. However, we can easily recognize Leonardo's statement as a forerunner of our contemporary Gaia theory, which sees the planet as a self-regulating and self-organizing living system.[8]

At the most fundamental level, Leonardo always sought to understand the nature of life. This has often escaped earlier commentators, because until recently the nature of life was defined by biologists only in terms of cells and molecules, to which Leonardo, living two centuries before the invention of the microscope, had no access. But today, a new systemic understanding of life is emerging at the forefront of science — an understanding in terms of metabolic processes and their patterns of organization.[9] Those are precisely the phenomena which Leonardo explored throughout his life. The unifying conceptual threads that interlinked his knowledge of macro- and microcosm were life's patterns of organization, its organic structures, and its fundamental processes of metabolism and growth.

**A systemic thinker**

Leonardo da Vinci was what we would call, in today's scientific parlance, a systemic thinker. Understanding a phenomenon, for him, meant connecting it with other phenomena through a similarity of patterns. This exceptional ability to interconnect observations and ideas from different disciplines lies at the very heart of Leonardo's approach to learning and research.

Leonardo's scientific work was virtually unknown during his lifetime and remained hidden for over two centuries after his death in 1519. His pioneering discoveries and ideas had no direct influence on the scientists who came after him, but during the subsequent five hundred years his conception of a science of forms would emerge again at various times.

During those periods, the problems he had struggled with were revisited repeatedly at increasing levels of sophistication, as scientists advanced in their understanding of the structure of matter, the laws of chemistry and electromagnetism, cellular and molecular biology, genetics, and the critical role of evolution in shaping the forms of the living world.

Today, from the vantage point of 21st-century science, we can recognize Leonardo da Vinci as an early precursor of an entire lineage of scientists and philosophers whose central focus was the nature of organic form. They include Immanuel Kant, Alexander von Humboldt, and Johann Wolfgang von Goethe in the 18th century; Georges Cuvier, Charles Darwin, and D'Arcy Thompson in the 19th; Alexander Bogdanov, Ludwig von Bertalanffy, and Vladimir Vernadsky in the early 20th; and Gregory Bateson, Ilya Prigogine, and Humberto Maturana in the late 20th century; as well as contemporary morphologists and complexity theorists like Brian Goodwin, Ian Stewart, and Ricard Solé.

However, none of the scientists in that lineage were aware that the great genius of the Renaissance had already pioneered many of the ideas they were exploring. While Leonardo's manuscripts gathered dust in ancient European libraries, Galileo Galilei was celebrated as the "father of modern science." One cannot help but wonder how Western scientific thought might have developed, had Leonardo's Notebooks been known and widely studied soon after his death.

**Deep ecology**

Leonardo did not pursue science and engineering to dominate nature, as Francis Bacon would advocate a century later. His science was a gentle science. He abhorred violence and had a special compassion for animals. He was a vegetarian because he did not want to cause animals pain by killing them for food. He would buy caged birds in the marketplace and set them free, and would observe their flight not only with a sharp observational eye but also with great empathy.

In the designs of his flying machines, Leonardo tried to imitate the flight of birds so closely that he almost gives the impression of wanting to become a bird. He called his flying machine *uccello* ("bird"), and when he drew its mechanical wings, he mimicked the anatomical structure of a bird's wing so accurately and, one almost feels, lovingly, that it is often hard to tell the difference.

Instead of trying to dominate nature, Leonardo's intent was to learn from her as much as possible. He was in awe of the beauty he saw in the complexity of natural forms, patterns, and processes, and aware that nature's ingenuity was far superior to human design. "Though human ingenuity in various inventions uses different instruments for the same end," he declared, "it will never discover an invention more beautiful, easier, or more economical than nature's, because in her inventions nothing is wanting and nothing is superfluous."[10]

This attitude of seeing nature as a model and mentor is now being rediscovered in the practice of ecological design. Like Leonardo da Vinci 500 years ago, ecodesigners today study the patterns and flows in the natural world and try to incorporate the underlying principles into their design processes.[11] When Leonardo designed villas and palaces, he paid special attention to the movements of people and goods through the buildings, applying the metaphor of metabolic processes to his architectural designs. He also considered gardens as parts of buildings, always attempting to integrate architecture and nature. He applied the same principles to his designs of cities, viewing a city as a kind of organism in which people, material goods, food, water, and waste need to flow with ease for the city to be healthy.

These examples of using natural processes as models for human design, and of working with nature rather than trying to dominate her, show clearly that as a designer, Leonardo worked in the spirit that the ecodesign movement is advocating today.

Underlying this attitude of appreciation and respect of nature is a philosophical stance that

does not view humans as standing apart from the rest of the living world but rather as being fundamentally embedded in, and dependent upon, the entire community of life in the biosphere.

Today, this philosophical stance is promoted by the school of thought known as "deep ecology."[12] Shallow ecology views humans as above or outside the natural world, as the source of all value, and ascribes only instrumental, or "use," value to nature. Deep ecology, by contrast, does not separate humans — or anything else — from the natural environment. It sees the living world as being fundamentally interconnected and interdependent and recognizes the intrinsic value of all living beings. Amazingly, Leonardo's Notebooks contain an explicit articulation of that view:

*The virtues of grasses, stones, and trees do not exist because humans know them... Grasses are noble in themselves without the aid of human languages or letters.*[13]

In view of this deep ecological awareness and of Leonardo's systemic way of thinking, it is not surprising that he spoke with great disdain of the so-called "abbreviators," the reductionists of his time:

*The abbreviators do harm to knowledge and to love...Of what use is he who, in order to abridge the part of the things of which he professes to give complete knowledge, leaves out the greater part of the things of which the whole is composed?... Oh human stupidity!... Don't you see that you fall into the same error as he who strips a tree of its adornment of branches laden with leaves, intermingled with fragrant flowers or fruit, in order to demonstrate the suitability of the tree for making planks?*[14]

This statement is not only revealing testimony of Leonardo's way of thinking, but is also ominously prophetic. Reducing the beauty of life to mechanical parts and valuing trees only for making planks is an eerily accurate characterization of the mindset that dominates our world today. This, in my view, is the main reason why Leonardo's legacy is immensely relevant to our time.

As we recognize that our sciences and technologies have become increasingly narrow in their focus, unable to understand our multi-faceted problems from an interdisciplinary perspective, and dominated by corporations more interested in financial rewards than in the well-being of humanity, we urgently need a science that honors and respects the unity of all life, recognizes the fundamental interdependence of all natural phenomena, and reconnects us with the living Earth. What we need today is exactly the kind of holistic science Leonardo da Vinci anticipated and outlined 500 years ago.

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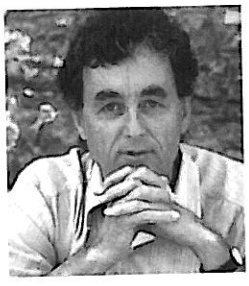

## The Centre for EcoLiteracy

Fritjof Capra is cofounder and president of the board of trustees of the Center for Ecoliteracy, a nonprofit based in Berkeley, California, dedicated to education for sustainable living. Best known for its pioneering work with experiential learning and integrating sustainability curricula in primary and secondary education, the Center has collaborated with schools and organizations from more than 400 communities across North America and in some 20 countries. Its work arises from the conviction that the best hope for learning to live sustainably lies in schooling that returns to the *real* basics: engaging with the natural world; understanding how nature sustains life; nurturing healthy communities; exploring the consequences of how we feed and provision ourselves; and caring about the places where we live and the people and creatures in them.

The Center was founded in 1995 by Fritjof, Peter Buckley, a philanthropist with a deep passion and concern for the environment and the education of children and Zenobia Barlow, director of the ecological think tank and international network of independent scholars and activists that Fritjof had founded to articulate an ecological paradigm and address problems in business and education from the perspective of systems thinking.

David W. Orr and Gay Hoagland joined the initial board. David, professor of environmental sciences and politics at Oberlin College, had recently written *Ecological Literacy: Education and the Transition to a Postmodern World.* Gay was executive director of the Bay Area Coalition for Essential Schools, a group attempting to bring innovative and equitable policies and participatory community to secondary schools.

When the board met for the first time, in the course of an hour it identified most of the elements that still guide its work. Fritjof advocated teaching ecological knowledge and systems thinking. Peter stressed the need to produce tangible outcomes leading to systemic change. Gay affirmed leadership and recognition that change is an organic process within the context of whole schools. David emphasized understanding the physical and biological patterns and cultural wisdom of particular places. Zenobia spoke for including a reverence for life and nurturing networks of relationships to carry visions to fruition.

The Center's working hypothesis was that applying key concepts of systems thinking can lead to sustainable change. CEL scouted for schools that (1) functioned as whole communities, (2) expressed the spirit of systemic school reform, (3) were committed to teaching ecological knowledge through project-based learning linked to particular places, and (4) desired to integrate curricula through school gardens, habitat restoration, or work with energy, shelter, or environmental justice programs.

The Center soon realized that effective change agents must shift nimbly among the different levels of scale in systems—from individual schools, to districts, to the communities and regions in which schools are embedded. Just as dynamic balance is maintained in healthy living systems, networks of relationships give stability and resiliency to social systems in the midst of continual change.

Out of its work with thousands of educators, the Center for Ecoliteracy has developed a framework for schooling for sustainability called "Smart by Nature," based on four guiding principles: nature is our teacher; sustainability is a community practice; the real world is the optimal learning environment; sustainable living is rooted in a deep knowledge of place. It applies to education the implications of the perceptual shifts that accompany holistic, systemic thinking: from the parts to the whole, from object to relationships, from objective knowledge to contextual knowledge, from quantity to quality, from structure to process, from contents to patterns.

Through its Smart by Nature™ initiative, the Center supports educators advancing sustainability in food practices, building and resource use, community connections, and teaching and learning. It offers seminars, consulting, professional development, and numerous publications, including *Ecological Literacy: Educating Our Children for a Sustainable World* (Sierra Club Books); *Smart by Nature: Schooling for Sustainability* (Watershed Media/University of California Press); and *Big Ideas: Linking Food, Culture, Health, and the Environment* (Learning in the Real World). The Center's website provides much downloadable resource materials, including its popular and newly revised Rethinking School Lunch Guide, curriculum and discussion guides to the films *Food, Inc.* and *Nourish,* essays by leading writers and experts, and stories of schools and organizations engaged in this vital work.

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