F R I T J O F   C A P R A

From the Parts to the Whole

Systems Thinking in Ecology and Education

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The cornerstone of our Ecoliteracy program is the parallel between ecological communities (that is, ecosystems) and learning communities (that is, schools). To understand the lessons of ecosystems and apply them to our human communities, we need to learn the principles of ecology, the "language of nature." We need to become ecologically literate.

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Once we really understand the principles of ecology—which we at the Center for Ecoliteracy identify as interdependence, diversity, partnership, energy flow, flexibility, cycles, coevolution, and sustainability—we realize that they can also be called principles of community. In our schools and other learning communities, we can apply these principles of ecology as principles of education.

The link between ecological communities and human communities exists because both are living systems, and this is where systems thinking comes in. The parallel between ecosystems and human communities is not just a metaphor. It is a real connection, because both are living systems. The principles of ecology are, if you wish, the patterns of life.

To understand these patterns, to understand living systems, we need a new way of thinking. The fundamental change in our way of thinking must be a shift of emphasis from the parts to the whole.

The emphasis on the parts has been called by various names, the best- known being “mechanistic.” This comes, of course, from “machine.” In order to understand a machine, you need to take it apart. This is Descartes’ celebrated method of analytic thinking, introduced in the seventeenth century, which has been an essential characteristic of modern scientific thought and has proved extremely successful. When you have a complex phenomenon or problem, you take it apart, reduce it to a number of small simple pieces that are easy to understand, study the mechanisms through which they interact, and then put them all together again, and you will understand the whole. This approach is also sometimes called reductionist thinking, because one attempts to understand the whole by reducing it to the study of its parts.

But you can't do this with living systems. If you take a living thing apart, you kill it. So the mechanistic/reductionist approach is not appropriate for living systems.

The emphasis on the whole has been called "holistic" thinking—from the Greek *holos,* the whole—or "organismic" thinking, because organisms are one of the main manifestations of living systems. It has also been called "ecological" thinking, because ecology is the study of the living communities to which this thinking applies.

Systems Thinking

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These are terms that were coined in the late nineteenth and early twentieth centuries. Around the 1930s, and from then on, the holistic perspective became known as "systemic" and the way of thinking it implies as "systems thinking." So today I would like to talk about the basic characteristics of systems thinking.

Systems thinking emerged during the first half of the century, especially during the 1920s, simultaneously in several disciplines. It was pioneered by biologists, who emphasized the view of living organisms as integrated wholes whose properties cannot be reduced to those of smaller parts. This school of biology was called organismic biology.

Systems thinking was further enriched by psychologists in the new school of gestalt psychology. *Gestalt* is a German word meaning "organic form." What these psychologists discovered was that living organisms do not perceive things in terms of isolated elements but in terms of integrated perceptual patterns—meaningful organized wholes that exhibit qualities that are absent in their parts. This is what they called a *gestalt.* The famous saying that "the whole is more than the sum of its parts" was actually coined by the gestalt psychologists.

The third discipline in which systems thinking emerged was ecology, which actually began as a science in those days. Ecology, as you know, is a very young science. The forerunners were the naturalists of the nineteenth century. Around the 1920s, the term "ecosystem" was coined, and with that term, ecology began as an independent science. Ecologists focused on the study of animal and plant communities, and again they encountered this irreducible wholeness. In particular, they observed networks of relationships—the web of life.

So biology, psychology, and ecology were the three fields in which systems thinking emerged. Finally, systems thinking emerged also in quantum theory, when physicists discovered that we cannot decompose the world into independently existing elementary units. As we shift our attention from macroscopic objects to atoms and subatomic particles, nature does not show us any isolated building blocks, but rather appears as a complex web of relationships between the various parts of a unified whole.

By the 1930s, most of the key characteristics of systems thinking had been formulated by organismic biologists, gestalt psychologists, and ecologists. In all these fields the exploration of three types of living systems—organisms, parts of organisms, and communities of organisms—had led scientists to think in terms of connectedness, relationships, and context. And this new thinking was also supported by the revolutionary discoveries in quantum physics in the realm of atoms and subatomic particles.

Although we can discern individual parts in any system, these parts are not isolated, and the nature of the whole is always different from the mere sum of its parts.

So let me now summarize the key characteristics of systems thinking and show you with a few examples how they apply to education.

Shift from the Parts to the Whole

The first and most general characteristic is the shift from the parts to the whole. According to the systems view, the essential properties of a living system—an organism or a community—are properties of the whole, which none of the parts have. They arise from the interactions and relationships between the parts. These properties are destroyed when the system is dissected, either physically or theoretically, into isolated elements. Although we can discern individual parts in any system, these parts are not isolated, and the nature of the whole is always different from the mere sum of its parts.

The new way of thinking, then, is thinking in terms of connectedness, in terms of context, and in terms of relationships.

To give an example, when you go out into nature and study ecosystems, you find that the various species there are all interconnected. They form a community and are interconnected through feeding relationships. The main patterns you discover are cyclical patterns. Energy and matter move in cycles through the ecosystem; all substances are continually recycled. The food chains that ecologists originally talked about are really food webs. They are networks, and there are cycles within those networks, which are feedback loops. All these are properties that can only be understood if you observe the whole ecosystem. If you split it into a number of species and make a list of those, you will never discover that there are these cyclical patterns that interconnect them. This is what we mean when we say that the system as a whole has to be studied, that it cannot be reduced to the properties of its parts.

The new way of thinking, then, is thinking in terms of connectedness, in terms of context, and in terms of relationships. Let us now explore how this new way of thinking applies to our schools.

Teachers: For children, the value of learning is greater when there's a connection to their life. It has to make sense to them within the context of their lives. In whole language learning, you don't learn the

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parts of speech, you learn it in a whole context.

FC: This is very relevant to ecology, because when we talk about ecological literacy, we take this metaphor from language. In ecology, as in language, everything is interconnected.

This is why we talk about an integrated curriculum. In a truly integrated curriculum, the understanding of connectedness is the central purpose. Once you have acquired the skill of perceiving patterns and connectedness, you can apply it anywhere. This is the most valuable skill I have learned in science: to perceive patterns of connectedness.

Now, what does thinking in terms of connectedness teach us about how to change our school systems?

Teachers: A teacher doesn't make a decision in isolation, so that it affects only her students. It involves parents, and so on.

FC: So the change doesn't happen just in the classroom, it also happens in the relationships between teachers and parents. One of the reasons we are working district-wide is that we believe sustainable change will only happen if the whole school district changes. Then, of course, you can go further and say that the district is embedded in the community of Mill Valley, and only if the community changes will the district change. But you do have to draw boundaries; you can't just say, "Well, it's all interconnected, so we can't start anywhere; it's hopeless." We need to draw boundaries, but at the same time we need to realize that these are fuzzy and permeable.

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Shift from Analysis to Context

Let me now talk about the second aspect of systems thinking, thinking in terms of context.

As I said earlier, the whole enterprise of Western philosophical thought has been mechanistic and reductionist, concentrating on the parts. The great shock of twentieth-century science has been that living systems cannot be understood by this method of analysis. This doesn't mean that we have to give up analysis. It's still very useful in many ways, but it is limited. It has to be supplemented by thinking in terms of context.

In a living system, the properties of the parts are not *intrinsic* properties, but can be understood only within the context of the larger whole. Thus the relationship between the parts and the whole has been reversed. The new rule is that in order to understand something, you don't take it apart; you put it into a larger context.

Let me give you an example. If you look around in nature and see a bird, or any other animal, you will see that it has feathers, or fur, certain colors, and certain other attributes. To understand these, you need to understand the animal in the context of its environment. You need to know what its habitat is, what its seasonal habits are, and so forth. Only then will you understand, for example, why a bird has certain colors. Then, if you know something about evolution, you will know how these colors originated and evolved. So you will understand the properties within the context of the environment of this animal and within its evolutionary context.

Kids learn when things are meaningful to them. They see the connections in their lives, in their families, in whatever concerns them.

So, systems thinking is "contextual," and this is the opposite of analytical thinking. Analysis means taking something apart in order to understand it; systems thinking means putting it into the context of a larger whole.

Now let's ask ourselves again: What does this mean in terms of teaching and learning? It would seem that meaningful knowledge is contextual knowledge. What does this conjure up in your mind?

> **Teachers**: Kids learn when things are meaningful to them. This means they see the larger context. They see the connections in their lives, in their families, in whatever concerns them. In understanding how children learn, there's a big emphasis now on going and interviewing parents, finding out about their home literacy, and understanding the child from his or her whole environment rather than just in the classroom.
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> **FC:** And if you remember, the whole constructivist approach says that the child is not an empty vessel but brings something to the learning situation, brings a context.
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> What about assessment? What does it mean for assessment that meaningful knowledge is contextual?
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> **Teachers:** Assessment needs to be embedded in the activity; it needs to match the kind of learning that's going on. The context and the process of learning, not the content, are what need to be assessed. And the reason to assess needs to be truly connected to the learning, not to some other agenda.

In the systems view, we realize that the objects themselves—the organisms in an ecosystem or the people in a community—are networks of relationships, embedded in larger networks.

Shift from Objects to Relationships

When you look at living systems and see that the parts can only be understood in terms of the context of the whole, you can go a step further. This was the dramatic event in physics in the 1920s. Physicists discovered that ultimately there are no parts at all. What we call a "part" is merely a pattern in an inseparable web of relationships. It is very useful to define parts, but this definition is often rather arbitrary and approximate and needs to be flexible.

Therefore, the shift from the parts to the whole can also be seen as a shift from objects to relationships. In the mechanistic view, the world is seen as a collection of objects, and the relationships between them are secondary. In the systems view, we realize that the objects themselves—the organisms in an ecosystem or the people in a community—are networks of relationships, embedded in larger networks. For the systems thinker, the relationships are primary. The boundaries of the discernible patterns, i.e., the "objects," are secondary. The world is a world of relationships, and within these relationships we draw circles around certain patterns, and then we say, "Well, this is what I call an object."

The more you think about the school district as a community, the more you will think about relationships, because that's what a community is.

For example, this network of relationships between leaves and twigs and branches I call a "tree." It's significant that when we draw a tree—and psychologists sometimes ask people to do this as a test—most of us don't draw the roots. Yet the roots are often as expansive as what we see in a tree. If we draw the relationships contained within the tree both above and below the earth, we get a very different picture. This is just one example of the shift of perception from objects to relationships. It is an extremely important part of systems thinking.

Now let's think again about our learning community in terms of relationships. What does this mean?

> **Teachers:** It vividly illustrates the importance of cooperative learning. In the curriculum, it is the idea that you need to teach the processes, how things interrelate. I think also of the relationships that adults have, how they work together in the community—the parents, the teachers, the administrators. It boils down to competition *or* cooperation.
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> **FC:** The more you think about the school district as a community, the more you will think about relationships, because that's what a community is. Nurturing the learning community means nurturing these relationships.

Shift from Hierarchies to Networks

When we look at these relationships and these networks within networks, we see that there are different levels. A striking property of living systems is their tendency to form multileveled structures of systems within systems. Therefore, another key characteristic of systems thinking is the ability to shift one's attention back and forth between systems levels.

Let's take our own organism as an example. At the smallest level we have cells, and each cell is a living system. These cells combine to form tissues, the tissues form organs, and the organs form organ systems (e.g., the nervous system or the digestive system). The whole organism is a network of all these relationships. Then the organism as a whole exists within societal relationships, within social systems, and within ecosystems. At each level, we have systems that are integrated wholes while at the same time they are parts of larger wholes. Throughout the living world, we find living systems nesting within other living systems.

Since the early days of ecology, these multileveled arrangements have been called hierarchies. However, this term can be rather misleading, since it is derived from human hierarchies, originally from the Catholic Church and now from the military and corporate worlds. These have fairly rigid structures of domination and control, quite unlike the multileveled order found in nature.

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The view of living systems as networks provides a helpful new perspective on the so-called "hierarchies" of nature. Since living systems at all levels are networks, we must visualize the web of life as living systems (networks) interacting in network fashion with other systems (networks). For example, we can picture an ecosystem schematically as a network with a few nodes. Each node represents an organism, which means that each node, when magnified, appears itself as a network. Each node in the new network may represent an organ, which in turn will appear as a network when magnified, and so on.

In other words, the web of life consists of networks within networks. At each scale, the nodes of the network reveal themselves as smaller networks under closer scrutiny. We tend to arrange these systems, all nesting within larger systems, in a hierarchical scheme by placing the larger systems above the smaller ones in pyramid fashion. But this is a human projection. In nature, there is no "above," nor "below"; there are no pyramids and no hierarchies. There are only networks nesting within other networks. So systems thinking includes a shift from hierarchies to networks.

This is not only a shift of perception, but also a shift of actual structures in a community. We need a shift in our organizational structures from hierarchies to networks. If we want to create a sustainable community, it is important to make sure that there is a free flow within a network; that there is a network of relationships that is nurtured.

Shift from Structure to Process

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All the systems concepts discussed so far can be seen as different aspects of one great strand of systemic thinking, which we may call contextual thinking. Contextual thinking means thinking in terms of connectedness, context, and relationships. Actually, the Latin root of the word "context" means "weaving together."

There is another strand in systems thinking that is of equal importance: process thinking. In the mechanistic framework of Cartesian science, there are fundamental structures, and then there are forces and mechanisms through which these interact, thus giving rise to processes. In systems science every structure is seen as the manifestation of underlying processes. Structure and process always go together; they are two sides of the same coin. Systems thinking is always process thinking.

So let's focus on process thinking and see what it means for a learning community.

We are not talking about a process where learning is the goal. Learning *is the process.*

Teachers: Constructivism says we build on prior knowledge, we assimilate and accommodate new ideas.

FC: Yes. This is an ongoing process, and it doesn't really matter who initiates it. If it's initiated by the kids, all the better. You just join the process and help manage the process of learning.

Teachers: We need to allow for approximations; it doesn't always have to be correct. There are gray areas; it's evolving all the time; there is not as much emphasis on the "right answer."

FC: This reminds me of what Gandhi said about peace: "There is no way to peace. Peace is the way." It's that kind of shift. We are not talking about a process where learning is the goal. Learning *is* the process.

Process thinking, by the way, also needs to be applied to the process of change and development in a learning community. Leadership is concerned with managing, facilitating, and guiding the process of change. This is very different from designing and mandating change, which has been shown not to work. It's *facilitating* the change process that works.

Open Systems

Let me now be a little bit more specific in terms of ecology and talk about what kind of processes we observe in ecosystems. This is an old question in the history of biology. For centuries it has been evident to biologists that biological form is more than just shape, more than a static configuration of components in a whole. There is a continual flux of matter and energy through a living organism, while its form is maintained. Systems theorists have coined the term "open systems" to describe the situation. All living systems are open systems, which means they need to feed on a continual flow of matter and energy to stay alive.

In organisms, this flow of matter and energy is the process of metabolism—taking in food, digesting it, using the energy to grow and maintain structures and to fuel activities, and discarding the waste products. In an ecosystem there is a corresponding flow of matter and energy throughout the community of plants and animals. In the process of photosynthesis, green plants take up energy from the sun, transform it into chemical energy, and use it to build complex organic substances out of minerals and water—proteins, carbohydrates, fats, etc. These are then taken up by the animals feeding on the plants and on other animals; and finally the animals' organic wastes (and ultimately the animals themselves) are reduced to inorganic substances by microorganisms, ending up as minerals to be taken up again by plants.

Thus there is a continual cyclical flow through the ecosystem, each organism passing on matter and energy and each maintaining itself in a state of dynamic balance as matter and energy flow through it. If you look at a bush out there, at its various leaves, you see that there's a constancy of form; and yet substances flow through it all the time. There is a dynamic balance; a constancy of pattern, of form, while there is continual structural change.

So let's think about a learning community as an open system. What corresponds to the minerals and the sunlight that are taken up from the environment?

> **Teachers:** Ideas, information, relationships. The school district is embedded in the community.
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> **FC:** Right. There is, of course, also a physical flow, because we eat in schools, we have electric light, computer terminals, and so on. All of this is the flow of energy and matter. But then there's the mental flow, the mental energy, if you wish, the flow of information. What happens when this flow is closed off, when the system closes itself off?
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> **Teachers:** It suffocates, it becomes dysfunctional. Like a dysfunctional family, it is closed off and has its own neurotic relationships without any connection to the outside world. Feedback loops are needed from all parts of the system, so there's a free energy flow throughout.
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> **FC:** Yes, this is a very important aspect. Ecological cycles all act as feedback loops. This is how a living system stays in balance.
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> **Teachers:** Instead of going around in the same cycles, what causes living systems to develop and evolve?
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> **FC:** Ah, here is where process thinking becomes tricky. There are two kinds of changes, and process thinking applies to both. There are the cyclical changes, and then there are developmental and evolutionary changes. The new thinking in systems science is that evolution is not just an adaptive reaction to changes in the environment. This is often important, but development and evolution are much more. They are intrinsic properties of life. All living systems have the ability to create novelty.
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> It would take me too long to get into more details here, but I want to emphasize that all that is part of process thinking.

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So these are the two big strands of systems thinking—contextual thinking and process thinking. Both are needed to understand the basic principles of ecology, the patterns of life.