# Teach Me To Think

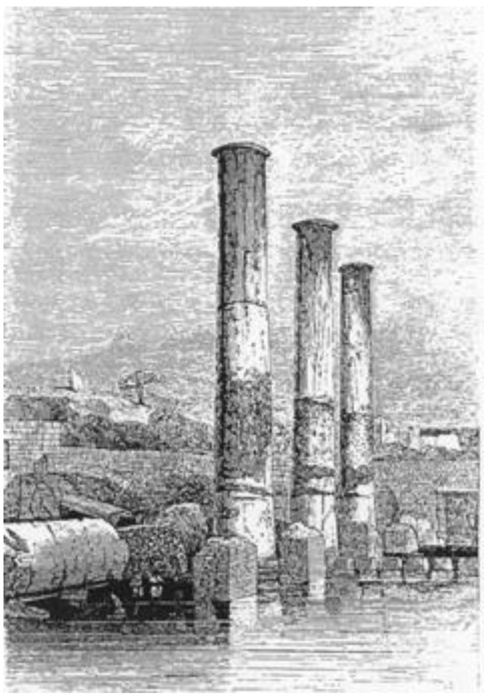
## Developing Thinking and Judgment in High School Science

By Craig Holdrege

This essay appeared in two parts in the journal *Renewal* (Fall-Winter, 2001 and Spring-Summer, 2002).

## Questioning

The ability to question lies at the root of thinking. When we truly think-and don't just mimic what another person tells us-the activity arises out of questions. Questions are the driving force of any thought process; they give direction, focus, and energy. If we're interested in helping students think, then we must help them learn to question themselves and the world.



The three columns of the "Serapis Temple." ( Reprinted from Structural Geology by John Dennis; New York: The Ronald Press Co., 1972)

One problem with our information age is that people "know" very much without ever having asked for this knowledge or, afterwards, questioning it. We know the earth moves around the sun, we know the earth is 4.5 billion years old, we know we breathe oxygen, we know genes determine heredity-we know, we know, we know. But ask ninth graders how they know any of these facts and you get blank stares and responses like, "I don't know, somebody told me that," or "I saw it on the Discovery channel."

The purpose of this question is not to embarrass students but to show them that most of us have no idea how we know what we know. In fact, we are believers in the "facts" of science. It's paradoxical that the scientific age, which began as a revolt against traditional belief systems, has become an age of the belief in science. We are ensconced in a "dogmatic slumber," to use Kant's phrase. One primary task of science teaching should be to help students awaken from a certain naïveté of childhood that can all too easily become a very firm dogmatic slumber in adulthood. Adolescents should feel continual scientific revolution.

To this aim, when I teach science classes beginning in the ninth grade, I emphasize that we shouldn't take any handed-down knowledge for granted; we need to question what we think we know. In this sense high school students need to become healthy skeptics (not cynics!). "How do I know this?" is the fundamental question. When we begin questioning in this way, we soon realize that we know very little. Although at first unsettling, this realization becomes exhilarating. And there is a person who can stand as an ideal for the students-Socrates, one of the great figures of western culture who was put to death for thinking independently. He was the man who always asked questions and was wise because he knew that he knew nothing. Starting from this Socratic base, we can begin to build more knowledge.

But this is difficult. If you think back on your experience of science classes in college, high school, or middle school, you may well remember, as I do, learning (and forgetting) myriad facts for multiple choice tests. This kind of learning is widespread in American education and is what my colleague Steve Talbott calls "fact-shoveling." Since most of us have grown up in this system, it's not easy to overcome the idea that the science teacher's main task is to teach loads of facts. And even worse is the reasoning that we must do this in high school to prepare for college. (Nothing like eating an appetizer of rocks to prepare for the main course of boulders.) So how do we overcome such a dead approach to science?

## Riddles-The "Serapis Temple"

One powerful and fruitful way to avoid feeding students stones is to present scientific phenomena through concrete examples that are riddles. Riddles engage the mind and stimulate questions. Riddles stir feelings, awakening wonder and interest. Riddles fire the will to find a solution. Riddles are wonderful. The most timeconsuming part of preparation for my lessons has been in search of good riddles to serve as the entryway into the process of learning science.

Let's take an example out of the ninth grade geology block. Rocks don't naturally interest everyone and the first time I taught the block I was scared to death that I was going to bore the students to death with things I was very excited about. But the riddle approach (along with fieldwork, which I won't go into here) saved the day.

In the eighteenth century, Italians began to excavate ruins from the Roman empire. In Pozzuoli, a village on the Mediterranean coast near Naples, the ruins of what appeared to be a temple were discovered. The tops of three large columns were found hidden by bushes, about a hundred feet from the sea. The columns were covered with foot after foot of compacted volcanic ash (tuff), volcanic rocks (pumice) and debris. Volcanoes surround the area and Vesuvius is not far away; it is an area with frequent earthquakes. The three columns turned out to be enormous-about forty-two feet high. Remains of many other columns were found and the ruins were given the name Serapis Temple. (Later archaeologists concluded that it was a market place.)

There was something strange about the columns (see figure). The lower twelve feet were smooth and uninjured, but the following twelve feet were not: the limestone was highly corroded. Looking carefully, the excavators found cavities with shells of saltwater mussels. These are mussels that bore into rock by dissolving it and then dwell in their self-made cavities. The upper eighteen feet of the columns were weathered, but in quite good shape.

If I've succeeded describing this discovery to the students in a vivid manner, I hardly even need to ask the question, What's going on here? It's as if the columns themselves were saying, Do you see that we are a riddle to be solved? The main question revolves around the twelve-foot band in the middle of the columns that is corroded and full of mussel shells. To the logical minds of ninth graders it is completely clear that the presence of mussel shells means that the columns were at some point in water. And they must have been in water for quite a long while, since the mussels had time to eat limestone away.

Here a process of question and answer begins, where the teacher may need to fill in more information to give the students a better orientation. But the students' conjectures and questions move the process along, which is a bit different in every class.

How did the columns get in water and why is there only of band of corroded limestone, with intact material above and below it? Most students think (as did the first geologists investigating this example) that the water level rose. If this were true, then sea level must have risen at least twenty-four feet, up to the top of the mussel-eaten band in the columns. Since the sea level is more or less horizontal and the Mediterranean Sea is connected to the Atlantic Ocean, the whole oceanic body of water covering the earth would have to have risen-perhaps due to melting of the ice caps-twenty-four feet. This would result in a continuous band of submerged coastlines all over the earth. But this is not the case. Even along the Mediterranean Sea coast there is no evidence for a general rise in sea level. Evidently it was a more local phenomenon.

So what is the alternative? The earth itself could have sunk. Usually someone conjectures that during one or more earthquakes the coast at Pozzuoli sank. The water level appeared to rise, but in reality the earth's surface sank at least twenty-four feet over a period of time. Although this is hard to picture, what else could have happened?

Now we have the columns standing in twenty-four feet of water. Why don't the mussels eat away the whole submerged part of the columns? This is a key moment for thinking -the ability to bring together different facts and see connections. I've seen students' faces light up when they "get it:" After, or while sinking, a volcano erupts and covers the area with twelve feet of volcanic ash and rock. This protects the lower twelve feet of the columns, so that the boring mussels have only the middle twelve feet to inhabit. The upper eighteen feet are above the water line; they weather but are inaccessible to the water-bound mussels. Slowly the mussels inhabited the twelve-foot band of the columns and ate away limestone, making caves for themselves.

At some point in time the coast must have risen, the water receded and the columns then stood, once again, on dry ground. Over time they were covered by ash and rock from other volcanoes and debris from earthquakes, so that only the tops were visible in the eighteenth century when they were excavated.

We’ve solved a riddle! Together we have reconstructed in our minds-with the aid of three "lowly" columns-remarkable movements of the earth's crust: first sinking, then lifting; and all this within historical times. At the conclusion of this discussion I feel a sense of success, when I see that the students are amazed at both what the earth does as well as at their own ability to think and tie together archeological and geological facts into a cohesive picture.

## Logical Thinking Anchored in Observation

How have the students trained their thinking by learning about the Serapis Temple? First, they have learned that questions are essential. Without asking questions they won't get anywhere. Secondly, they learn that to answer questions you have to go through a process that takes time and energy. They can't sit back and become enlightened. When they come up with conjectures, then these conjectures have to be brought in relation to the facts at hand. Do they fit? They have to think through consequences: if the sea level rises 24 feet, then what would happen on all coastlines? They then see that a particular train of thought doesn't make sense and try a different pathway.

Often students who are very quick intellectually are also satisfied with answers that don't hold up under further scrutiny. Considering an example such as the Serapis Temple columns slows down and extends the thought process so that it can become more conscious. We move from one phenomenon to then next, testing our thoughts at every step. Sometimes we rush ahead only to realize we've lost the phenomena; so we go back and reconsider. Thinking learns to be disciplined and a core element in this discipline is learning that we need to observe very carefully and be faithful to these observations. Any training of thinking is a training of observation as well (and vice versa).

In adolescence it's very important for students to experience that they can solve riddles. That their questions can be answered. This gives them the confidence they need to feel in their mental powers: I can understand the world. This is not the same thing as the ability to make quick and cutting judgments, a capacity that comes as a kind of adolescent birthright. I have often felt that there is no way to compete with the sharpness of a ninth or tenth grader's intellect, which comes out most strongly in their ability to argue. But this capacity to argue and judge often wells from a raging current of moods, likes, and dislikes that can cover up the real idealism they to bring into the world. So what the students need to learn-and that is an essential task in the high school-is to base their judgments on interactions with the world and not just on their own predilections. This is why studying the external world in science classes is so healthy.

Through teaching examples of scientific discovery, the students also learn to see science as a product of human activity. Science always starts with riddles like the three columns. Taken in a purely external way, the columns are just things we could pass by and shrug our shoulders ("so what"). But if we look and question, this static outer appearance transforms in thought into a lively movement. The students begin to see through the columns a world of becoming. They look, so to speak, with their mind's eye into the past by reading the present carefully and intensely. This is vastly different from learning in a geology class the "fact" that the earth's crust moves up and down, illustrated by a few cursory examples. Such "knowledge" remains external to the human soul and is one reason many people learn to dislike science in school. But if the students themselves reconstruct out of the present the past, then they are involved. They know how geological knowledge about the earth's past comes about because they were engaged in a process.

This is a very satisfying experience. And part of that experience is knowing that they don't know all the answers. There is always more to investigate. This experience is the entryway into complex and, then, holistic thinking.

## Complex Thinking: The Germ Theory of Disease

As thinkers we have a tendency simplify matters. Just because a train of thought is logical and clear does not mean it does justice to the phenomena. In fact, when the succession of thoughts becomes exceedingly precise and consistent in itself, we can be quite sure that we're losing sight of the richness of the phenomena we're trying to illuminate. Especially in the ninth and tenth grades, when students should gain confidence and discipline in their thinking abilities, we can live with a certain degree of oversimplification since we're training "thought muscles." But in the eleventh and twelfth grades we can begin to challenge the students more.

By taking different points of view to consider any given phenomenon or problem, students learn that the world is complex and that we need to adapt ourselves to this complexity. Otherwise we'll end up with schematic notions, or even worse, caricatures of reality. I believe Rudolf Steiner had this task in mind when, in speaking about the biology curriculum in the eleventh grade, he said that the teacher should emphasize mutual dependency or reciprocal causation (Wechselursachenverhältnis) and go beyond what we call today linear causality (meeting with teachers, June 21, 1922).

I'd like to illustrate complex thinking by considering the germ theory of disease, which I often discuss in an eleventh grade biology block. This is an especially good topic because it not only challenges the students' mind and opinions, but also gives them a picture of how science actually develops. Again, I avoid a general discussion of the topic and use instead historical examples that can capture the students' interest.

Cholera is a deadly disease that spreads in epidemics. People who become ill with cholera suffer severe diarrhea and vomiting. Losing such large quantities of bodily fluids over a short period of time-hours to a couple of days-leads to dehydration and, if nothing changes, death. 19th century Europe witnessed numerous cholera epidemics. In 1854 a cholera epidemic befell the city and environs of Munich, Germany. Max von Pettenkofer, a medical doctor and professor at the University in Munich, was asked to investigate the epidemic. He began by making a precise map of the outbreak. He found that parts of the city were being ravaged while others were spared. Areas near or along creeks, rivers, and canals as well as low-lying areas near water were especially hard hit. On hills and near watersheds the incidence of cholera was much lower. He also discovered that where the soil was porous there was more cholera than in areas with poor drainage, where the water ran away more on the surface rather than seeping into the ground.

Pettenkofer noticed that the cholera areas were often poor and filthy. The air was filled with the horrible stench from open sewage pits and outhouses. "How gross!" say the students. They don't realize that American and European cities only began to have central sewage systems beginning in the late 19th century. The sewage pits were usually not sealed and the contents seeped into the soil. Wells were often contaminated with sewage. Pettenkofer was soon convinced that the interplay of excrement and water was a major factor in the cholera epidemic.

He didn't believe, however, that cholera was simply being passed from one person to the next. He observed many cases in which only some members of a family became ill, and doctors and other caregivers, who regularly came into bodily contact with ill people, usually did not become ill. Evidently, each person has a physiological disposition or constitution that makes him or her more or less susceptible to the disease. Pettenkofer concluded that the proximity to water, unsanitary conditions, and poor health conditions were together responsible for cholera. He worked hard to change these conditions and is often considered one of the fathers of public health and hygiene. Through his efforts, Munich became one of the first cities to install centralized sewage and water systems. Everywhere where sanitation increased, cholera ceased to be a problem.

Another German medical doctor and scientist, Robert Koch, was also working to find what caused cholera. Koch traveled to Egypt and India to investigate outbreaks of cholera in the early 1880s. He performed autopsies on the bodies of people who had died of cholera. In every case he discovered comma-shaped bacteria in the intestinal walls. He never found these bacteria in healthy people. Since intestinal dysfunction brings about the severe diarrhea in cholera, couldn't these bacteria be causing the disease? Is Koch's discovery a proof of the germ theory of disease? Since all the students "know" (recall the problem I described at the beginning of this article) that "germs" (bacteria and viruses) cause disease, most students think, "yes." But with prodding, the students can recognize there is a still a question. Just because Koch found the bacteria in the corpses, doesn't mean they caused the disease. Not only that, I've had students say, the bacteria might be an effect of the disease: because people are sick, bacteria can thrive in them. We don't really know-and Robert Koch didn't either.

Koch was an extremely careful and conscientious scientist. He was not prone to making overblown claims and wanted facts to be his judge. So he took infected tissue and learned how to grow the bacteria in laboratory cultures. (This was a momentous step forward in the history of bacteriology; most techniques for growing bacteria were discovered and perfected by Koch and his assistants.) Koch then injected animals-mice, rats, guinea pigs, rabbits-with the bacteria. They usually died of cholera-like symptoms. He isolated the bacteria from the intestines of the dead animals, cultured them and injected other animals, who again died. He repeated this process of isolation, culturing, and injecting again and again. To his mind, Koch showed that the comma-shaped bacteria were clearly causing cholera. This was 1883.

Koch had observed in India that people were drinking from the same water in which they bathed, washed clothes, and children defecated. He concluded that the bacteria-which are excreted in large amounts in the diarrhea of the sick-are spread from person to person, which is what causes an epidemic.

Pettenkofer, while not denying the existence of the bacteria, did not believe that they were the sole cause of the cholera. He was so convinced of his opinion-which was based on years of work and experience-that he decided to do an experiment on himself. He would drink a culture of the bacteria to bring to an end what he considered to be an irrational fear of bacteria. He had a fresh culture of cholera bacteria sent to him. It contained about a billion bacteria. Before ingesting it, he drank bicarbonate solution to neutralize the acid in the stomach that normally kills bacteria-he didn't want any critics saying afterwards that he hadn't done a thorough experiment.

So Pettenkofer drank a culture of cholera bacteria. The next day he awoke and felt fine and was happy to speak with reporters at his home, who had expected to find him dead. Three days later he had strong diarrhea, but it soon subsided and he never fell ill. (Soon thereafter, one of his assistants repeated the experiment with similar results, except that he became feverish.)

A lively classroom discussion usually follows this description. "Wasn't Pettenkofer stupid?" "But he survived!" "He was just lucky!" When things have calmed down, we can begin to sort out the situation. What did Pettenkofer prove? He showed that the cholera bacteria are not the sole cause of cholera; if they were, he would have died. Did he prove that the bacteria have nothing to do with cholera? No. Rather, his experiment was a proof of his idea that the individual constitution is a very important factor in contracting the disease. It seems that both Koch and Pettenkofer were partially right and partially wrong. Together, the facts they pointed to provided a correct picture of infectious diseases: they are transmitted by the bacteria (or viruses), but whether the person becomes ill or not is dependent on his or her susceptibility. Only the interplay of these two factors-germ and constitution-mediated by the environment gives rise to an infectious disease.

I go on to discuss with the students that we must be very careful when using the word cause in biology. I present other examples, sometimes quoting excerpts from scientific articles that use the word cause. The students are now more critical and wakeful listeners and usually see themselves that what is called a cause is usually only a partial cause.

Closer investigation always shows that biological phenomena are caused by the interaction of multiple factors. For this reason, I give the students a radical suggestion: to ban the word cause from biological and medical vocabulary. Its imprecise usage fosters a great deal of unclarity. We would do well to substitute the word condition for the word cause. We can say that bacteria present a necessary condition for the outbreak of cholera, but alone they are not sufficient to do so. A weak constitution is also a necessary condition. All the necessary conditions taken together can be said to cause the disease. When the students have understood this, they have entered the school of complex thinking. They see that we need more refined concepts to grasp the world adequately.

Complex thinking is not satisfied with simple answers. It always seeks to find the boundaries of theories and explanations in order to delve deeper into the matter. In the best sense of the word, complex thinking is critical. But it is also comprehensive and flexible in the continual search for new vantage points from which to illuminate a problem.

There are many courses in the $11^{th}$ and $12^{th}$ grades in Waldorf Schools that are especially well suited to cultivate complex thinking (which doesn't mean it can't be practiced in every subject). I think, for example, of the history of atomism in eleventh grade chemistry, where students can learn about the evolution of atomic models and overcome the billiard ball pictures they carry in their minds. Or the projective geometry block, where the students confront concepts like infinity and duality (polarity) that stretch their minds in a wonderful way. At Hawthorne Valley School we instituted an ecology block in the eleventh grade. Ecology is the scientific discipline that should (but unfortunately often doesn't) make complex thinking fundamental to its teaching, since ecology has everywhere to do with complex, changing relations. Most ecological problems are the stark testament of our inability to think complexly-or one could also say ecologically.

## Holistic Thinking

The flexibility of thought we exercise in complex thinking is a prerequisite to understand living phenomena. But it is not enough. I sometimes begin the twelfth grade zoology block by showing the students a picture of an animal they know, say a cow, and then ask them how they would scientifically explain a cow. The question catches them a bit off guard. But someone usually comes up with a comment such as, "the cow has horns to protect itself." Once this kind of answer has fallen, a cascade follows. The cow has a tail to kill insects, it has wide-set eyes to see its prey, it has big molars to grind grass, it has hooves to stand for long periods of time, it has a four-chambered stomach to digest grass. And so on. We go through many characteristics and explain each one by finding some function it fulfills. This kind of explanation is relatively satisfying.

Whether they know it or not, the students have applied a popular form of Darwinian thought to the cow. I tell them how in Darwinian theory today researchers look at the different traits of an organism and consider them to be survival strategies. The "reason to be" for any given characteristic is that it allowed the cow to survive. On this theory, each characteristic arises separately and by chance, but because it is supportive of the animal's survival and its ability to reproduce, it is maintained in evolution.

When we've painted this picture I ask the students to look at what the cow has become conceptually for them. The answer is: an agglomeration of separate characteristics. The cow as a cohering, whole organism that has these characteristics has disappeared. But don't we want to understand the cow? The students can see a dilemma. We need to analyze in order to come to any kind of understanding, otherwise we remain in dreamy generalities. But if we lose the whole animal in this process, then what have we gained? The question is, can we learn to move beyond analysis and discover how the seemingly separate parts of an organism are in fact related to each other within the context of the whole creature? This is the underlying task of the twelfth grade zoology block.

It's an intriguing fact that while Darwinism has led to an increasingly atomized view of organisms, Charles Darwin himself was keenly aware of the "exquisite adaptation of one part of the organization to another part" (Origin of Species, chapter 3, p. 114). The wings of a bird are of course wonderfully adapted to flight. But the capacity to fly is also expressed in its bone and muscle structures, in its lungs and circulatory system, in its senses and nerves; in short-in every detail of the bird's anatomy, physiology and behavior. All of these features are, moreover, in continual interaction and dependent upon each other. For example, a bird has large flight muscles on its breast. The breastbone, correspondingly, becomes the largest bone in the body to support these muscles. The circulatory system is, in turn, built such that these muscles receive large amounts of blood during flight. The further you investigate the more you come to see how every part is inextricably entwined with every other part. Goethe formulated this relation succinctly:

> All its parts have a direct effect on one another, a relationship to one another, thereby constantly renewing the circle of life; thus we are justified in considering every animal physiologically perfect…. Nothing can be added to one part without subtracting from another, and vice versa. (Goethe, p. 121)

This wisdom-filled relation of the parts of an organism to each other is known in the science of comparative morphology as the law of compensation, or the law of the correlation of parts (after Cuvier).

It is one thing to establish the fact that organisms are fully integrated beings; it is another matter to understand in a concrete case how everything in an organism hangs together. A true science of the wholeness of organisms is still in its infancy because it puts new demands on our thinking capacity. Holistic thinking demands that we immerse ourselves in details and then move from detail to detail, but with an eye toward the whole organism that expresses itself in every part.

Some of my most rewarding moments of teaching occur when I succeed in taking this approach with students. Why? First, because we are involved in a process of real discovery. I tell the students that we're searching for an understanding of animals and plants that they won't find in textbooks. Together we may find relations that have not yet been discovered. Secondly, because when those moments of insight arise-aha! I see how these two things are connected-they are deeply satisfying. We have touched something essential. The animal or plant has begun to reveal its deeper nature.

Let me give an example from the twelfth grade zoology block. While amphibians (frogs, toads, newts, and salamanders) all lay their eggs in water, reptiles (lizards, snakes, turtles, and crocodiles) lay their eggs on land. This fundamental difference between these two groups of vertebrates is mirrored in their overall anatomy, physiology, and behavior. The eggs of amphibians are protected by a jelly-like mass and float weightless in water. The growing embryos take oxygen out of the water and nourishment from the yolk-rich egg. In contrast, the eggs of reptiles are covered with a dry, papery-like shell (which is hard and calcified in crocodiles, like in birds). Within the shell the embryo floats in its own egg-made fluid within the so-called amniotic cavity. The protection and buoyancy the amphibian embryo receives from its watery environment, the reptile creates internally through an additional embryonic organ. Even when an animal like a reptile lays its eggs on land, its life begins in water-but in its own self-produced amniotic fluid.

The comparatively isolated reptile egg, resting in sand, soil, or leaves, has another "problem" compared to amphibians: In the amphibian embryo, gases and waste products diffuse in and through the medium of the surrounding water. The reptile compensates for this loss of connection to its immediate surroundings by creating an additional internal organ-the allantois. This blood-rich organ functions as an embryonic lung as well as a bladder that collects urine.

The more immediate relation of amphibians to a watery environment extends into their further development. Amphibians go through a fish-like stage as larvae (tadpoles). They breathe through gills and swim limbless, propelled by a tail fin. They then experience a striking metamorphosis into adults. They lose their gills and develop lungs, limbs develop and, in the case of toads and frogs, the tail is completely reabsorbed. Only after this metamorphosis can an amphibian leave its natal pond and venture on to land. (Some amphibians remain their whole lives in water.)

Amphibians have moist and permeable skin. In fact, they breathe more through their skin than they do through their lungs. The skin not only lets gases in and out, but also moisture. For this reason amphibians remain bound to a moist environment even if, as is the case with many frogs and toads, they spend most of their adult lives out of water. When subject to dry air, a frog or toad will lose large amounts of its body moisture content. When it comes into contact with water again, the body quickly replenishes fluid loss by drawing water in through its skin (osmosis). A dehydrated frog need not drink with its mouth, it can just stick a foot in water and suck up all the water it needs!

Every year in spring the amphibian's strong relation to water comes into play when the adult returns to the pond where its life began. The female lays its eggs that are immediately fertilized-the water once again acting as a medium-by the male's sperm.

Just as the amphibian's connection to water shows itself in its anatomy, physiology, and behavior, so does the reptile's origin in a self-contained egg on land find expression in its other characteristics. In contrast to the amphibian, the reptile hatches from its egg as a small version of the adult. It already has a thick, cornified, and dry skin. The skin is virtually water-impermeable. Just as the reptile egg becomes independent from an external watery environment, carrying its own fluid, so does the adult reptile's skin allow it to detach itself from the need for direct and ongoing contact to water. For this reason reptiles can live in very arid climates by conserving body fluids for long periods of time and producing very concentrated urine to minimize water loss. Their whole physiology is built around the independence from water.

Of course, many reptiles are water-dwelling-marine turtles, crocodiles and alligators, water snakes, and so on. They nonetheless lay their eggs on land and have thick, impermeable skins. In this way they are primary land creatures that then seek the water after hatching. Through their skin they remain in a sense detached from water within water, unlike amphibians.

The reptile's skin is not only impermeable to water but also to gases. Correspondingly, its lungs develop more pockets and a greater surface area to take in the inhaled air. Lung development is always correlated with the development of the circulatory system. In reptiles the heart has four chambers through which arterial and venous blood coming from the lungs on the one hand and the rest of the body on the other, remains completely (in crocodiles) or mostly (in other reptiles) separate. In contrast, amphibians have three-chambered hearts in which the blood coming from the lungs and from the rest of the body is mixed together. Again we see the quality of interpenetration in amphibians and increasing separation and differentiation of internal organs in reptiles.

Through such considerations, the students see how each group of animals is a unified whole. They see how the amphibian's life and structure are imbued with an intimate and open relation to water, not only in general terms, but in all details of reproductive behavior, embryonic development, skin, breathing, and circulation. The reptile has closed itself off from the immediate interdependency with the watery world and every facet of its being speaks of this separation and the corresponding development of inner functions and structures. The understanding of each group is heightened by the contrast to the other. This is why I often work with comparisons, so that the unique features of each animal stand out much more distinctly.

To come to this kind of understanding demands that we not only register the characteristics, but that we actively recreate them in our imaginations. We need to form a saturated inner picture, say, of the amphibian embryo floating in water, surrounded by a clear jelly that mediates the exchange of substances and gases through the water. When we have built up this picture and then consider the amphibian's skin-thin, moist, and permeable-we see the same quality in another characteristic. This is holistic thinking.

Holistic thinking is so difficult because in our society we learn on the one hand to hold facts at a distance and on the other hand to use our imaginations in making pictures that have no relation to the external world. We don't bring the two together. Coleridge distinguished between fancy, which involves arbitrary picture making, and true imagination, which engages the world. In holistic thinking we need true imagination. We enter into a given phenomenon with our active imaginations and form pictures, we move to the next feature and build a new picture. In this sustained, wakeful process the wholeness of the creature can light up. This light can then illuminate further characteristics as one deepens the study of organism.

The wonderful thing about this process is that otherwise isolated details become interesting, because they help shed more light on the organism as a whole. For example, only when I'd begun to grasp the underlying difference between amphibians and reptiles, did the way they make poisons begin speak, that is, to tell me something about the animals themselves. There are very poisonous tropical frogs that secrete their poisons through glands that are distributed over their whole skin. When you pick them up and have a small wound on the hand, the poison can get into your blood and poison you. In contrast, the reptiles have poison glands concentrated in the roof of the mouth and must actively bite you and penetrate your skin with their fangs, through which the poison is injected into you. Isn't this the same contrast we have seen before, but now showing a new nuance?

To my mind, one of the most important tasks of Waldorf education is to reach this level of understanding in the eleventh and twelfth grades. It is not for nothing that in developing the curriculum with the teachers of the first Waldorf school, Steiner suggested that many of the twelfth grade main lesson blocks have the character of an overview. We can build on the knowledge gained in previous years and pull it together to see overriding trends-in history, the evolution of consciousness; in chemistry, the different kinds of substances and transformations that characterize the different kingdoms of nature; in biology, the overview of the major phyla and classes of plants and animals. And so on.

Nothing is more important than to help the students school their abilities to see relations and connections, to see how things fit together in the world. This is precisely the capacity humanity needs to find creative solutions to the myriad problems we create that lead to a dissolution, rather than to a building-up of the world.

## Bibliography


Bulloch, William. 1979. The History of Bacteriology. New York: Dover. (Originally published in 1939.)

Coleridge, Samuel Taylor. 1975. Biographia Literaria. London: J.M. Dent & Sons Ltd. (Coleridge wrote these essays between 1800 and 1817.)

Darwin, Charles. 1979. Origin of Species. London: Penguin Books. (Originally published in 1859.)

Dennis, John. 1972. Structural Geology. New York: The Ronald Press Company.

Evans, Alfred. 1973. Pettenkofer Revisited. Yale Journal of Biology and Medicine Vol. 36, pp. 161-176.

Goethe, Johann Wolfang von. 1995. Scientific Studies. Edited by Douglas Miller. Princeton: Princeton University Press.

Holdrege, Craig. 2000. Addressing Contemporary Issues in the High School: The Example of Human Cloning. Renewal Fall/Winter, pp. 28-31.

Howard-Jones, Norman. 1984. Robert Koch and the Cholera Vibrio: A Centenary. British Journal of Medicine Vol. 288, pp. 379-381.

Knight, David. 1961. Robert Koch. New York: Franklin Watts.

Lechevalier, Hubert and Morris Solotorovsky. 1974. Three Centuries of Microbiology. New York: Dover.

Lyell, Charles. 1990. Principles of Geology Volume I. Chicago: University of Chicago Press. (This book was originally published in 1830 and is a classic in geological literature; it contains a wealth of examples, including the Serapis Temple.)

Ogawa, Mariko. 2000. Uneasy Bedfellows: Science and Politics in the Refutation of Koch's Bacterial Theory of Cholera. Bulletin of the History of Medicine Vol. 74, pp. 671-707.

Rauthe, Wilhelm. 1996. Steps in the Development of Thinking. Waldorf Science Newsletter Vol. 3 #4, pp. 8-12.

Schad, Wolfgang. 1982. Die Vorgeburtlichkeit des Menschen. Stuttgart: Verlag Urachhaus.

Steiner, Rudolf. 1998. Faculty Meetings with Rudolf Steiner Vols. I and II. Great Barrington, MA: Anthroposophic Press. (These meetings were held between 1919 and 1924.)

Steiner, Rudolf. 1996. Education for Adolescents. Great Barrington, MA: Anthroposophic Press. (Lectures held in 1921.)

Wieninger, Karl. 1987. Max von Pettenkofer. Munich, Germany: Heinrich Hugendubel Verlag.