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Teaching Critical Thinking Skills in the Biology & Environmental Science Classrooms

Daniel D. Chiras

TRULY effective teaching today demands a blend of approaches to impart facts and concepts vital to a student's intellectual development. In today's world, however, education must provide more than facts and a few insights. It must furnish students with skills that help them become better thinkers. Part of becoming a better thinker is learning to become a critical thinker.

Critical thinking has been defined in many ways by many different people (Causey 1991; Schmidt, Shelley & Bardes 1989). A biological scientist, for example, may define critical thinking as a process by which one subjects research findings and theories to examination, looking for consistencies and inconsistencies in logic, alternative interpretations, and subtle but pervasive biases that may have led to erroneous conclusions. When examining an experiment, a biological scientist scrutinizes the methodology in light of accepted practices of science. In history and political science, critical thinking is often viewed as a process in which one attempts to distinguish facts from judgment. Regardless of the discipline, the process of critical thinking is remarkably similar.

Professor Larry Wilson from Miami-Dade Community College, a leading proponent of teaching critical thinking in the science classroom, defines critical thinking as the most ordered kind of thinking of which humans are capable. Ordered thinking requires certain skills that allow us to analyze the results and conclusions of experiments, facts and problems in a methodical fashion. Critical thinking skills, therefore, help students assess the accuracy of information presented to them, but also helps students avoid illogical thinking and other common mistakes in reasoning.

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Critical Thinking as a Subtheme in the Science Classroom

Teaching critical thinking skills in the science curricula is vital to the goal of improving science literacy and offers science teachers an unparalleled opportunity to impart skills of extraordinary value to their students—skills that are useful not just in the science classroom, but in all other disciplines, including government, economics, sociology, literature and law. Critical thinking lessons learned in the science classroom also impact students' lives long after they have departed from formal education by providing a means by which they can analyze a wide variety of issues they will confront in their daily lives.

Unfortunately, the massive increase in factual information in the past 20 years has often meant less time for teaching skills and more time spent on facts. Thankfully, many educators recognize how essential critical thinking skills are to a student's intellectual development and are beginning to fill the void by introducing the critical thinking skills in the classroom through lecture and carefully planned exercises. While this may result in a slight decrease in time spent on formal course content, the payoff in the long run could be extraordinary (Tyser & Cerbin 1991). Some proponents of teaching critical thinking argue that if school systems spent more time teaching study skills as students progress through the educational system, our pupils would become more efficient learners. Under these circumstances, it is conceivable that critical thinking could be offered without sacrificing course content—that is, the amount of factual and conceptual material presented in class (Svinicki 1990).

In this article, I will outline some "rules" of critical thinking and will offer a few suggestions for "teaching" them. Before starting, however, a word of caution: Critical thinking is an active process. It requires student participation. The more your students are involved in the process, the more they will get out of it. To encourage participation, you might begin by asking your students to suggest a list of topics *they* would like to consider—that is, find out what's on their minds.

Principles of Critical Thinking

First Principle: Don't mistake ignorance for perspective/Gather complete information. One of the most important—and most often violated—principles of critical thinking is thoroughness—that is, gathering of all available facts on a subject under scrutiny. Obviously, thinking requires facts, and students must recognize that faulty thinking and erroneous conclusions often stem from inadequate factual knowledge.

A class exercise to underscore this principle might be appropriate. Here's a suggestion: Provide students with a "slanted" set of facts (or research papers) on some subject such as the effects of urban air pollution on lung cancer. (Teachers should choose topics they know well or consult with fellow teachers to find appropriate examples.) After your students study the results you present (or read the assigned papers), ask them to read some contradictory studies (which you then provide), or ask them to check the literature on their own to see if they can find contradictory studies. (On this topic, you will find scientific studies that show a connection between urban air pollution and lung cancer and others that show no relation.) After doing this, ask students how the new information affected their initial conclusion. A few times through this exercise and the point will be well made: Gathering complete information is essential.

Second Principle: Understand and define all terms. Science requires students to master many terms and concepts essential to one's understanding of theories and current controversies. As teachers, we can help illustrate the value of understanding terms and concepts of science by asking students to examine articles/news reports in newspapers, magazines and television. Here they will encounter some writers who make broad generalizations that, upon closer examination, prove to be misleading.

To illustrate, consider two examples. The first is solar energy. It is not uncommon to encounter categorical statements in the press disparaging solar energy as "uneconomical." But is this true?

Ask students to look into the issue in more detail. What they will invariably find is that there are at least five different solar energy technologies: passive solar heating, photovoltaics to generate electricity, active solar hot water, solar thermal electric and solar cooling. After students understand the details of each technology, ask them to study the economics of the different options. If they do their homework carefully, they will find that some of the technologies, like solar thermal electric, are cost competitive with nuclear electricity. Passive solar heating can compete economically with electric heating, and photovoltaics can be cost competitive in certain applications—for example, in remote villages in Third World countries or in cases where homes are built one-half mile or more from existing electrical lines. The other technologies are generally not economical.

Table 1. Principles of critical thinking.

1. Gather complete information.
2. Understand and define all terms.
3. Question the methods by which facts are derived.
4. Question the conclusions.
5. Look for hidden assumptions and biases.
6. Question the source of facts.
7. Don't expect all of the answers.
8. Examine the big picture.
9. Examine multiple cause and effect.
10. Watch for thought stoppers.
11. Understand your own biases and values.

Understanding that the term "solar energy" is not just one technology, but a variety of them, may help students to be more critical thinkers and to avoid falling into the "ignorance trap."

A similar example from biology is cancer. Cancer is often talked about as if it were one entity, when, in fact, there are many types of cancer with many different causes. Broad statements like "cancer is on the rise" beg for a careful, discriminatory definition.

In this case, it turns out that the general assertion is correct. Cancer is on the rise. Upon closer examination, however, one finds that the overall *number* of cancer deaths is on the rise largely due to a rise in lung cancer. Interestingly, the incidence of many other forms of cancer has stabilized or decreased. In addition, since cancer is "a disease of old age" it is necessary to adjust cancer incidence statistics for changes in the age distribution of the population. When this is done, we find that all types of cancers (excluding lung cancer) have been declining since 1950 (Eaton 1991).

Third Principle: Question the methods by which facts are derived. In a biology classroom, critical thinking requires efforts to scrutinize the methods by which facts are derived. The first question we must ask is: Did the facts come from carefully controlled experiments or were they derived from random observations? If they came from experiments, were the experiments performed correctly?

A few minutes of class time spent on the prerequisites of good experimentation is well worth the effort. At this time, it is important to point out the need for a control as well as an experimental group in most experiments and to explain how the two groups are treated. It is also important to point out that good experiments also require an adequate number of subjects to be sure that observed effects are real.

A few simple classroom experiments will help show the importance of properly carrying out an experiment. Teachers can have students run experiments on a small number of subjects (plants or animals), then repeat them with larger groups to see if the results are the same. Pulse rate or height are two possible measurements that lend themselves quite well to classroom discovery.

Finally, it is important to point out to students that in science confidence in experimental results demands repetition—experimental verification of the results of initial work. Along this line, we must advise our students to be wary of preliminary results (data announced before all of the data are in) and early results coming from the first publication of a study. All-too-often, follow-up studies reveal the inadequacy of preliminary and early results. The cold fusion debacle is a good example. Teachers might assemble the news reports on cold fusion, then place them in chronological order. Students should be encouraged to study the reports in order of publication. As they do, they will first witness the initial euphoria based on the results of early experiments which, when subjected to further research, turned out to be highly questionable.

Fourth Principle: Question the conclusions drawn from facts. When analyzing any scientific study, issue or argument, it is important to determine if the facts really support the conclusions. One way of fostering this skill is to ask students to look for alternative conclusions that could be made from the same facts. Consider this example: One of the earliest studies on lung cancer showed that people who ate large amounts of table sugar (sucrose) had a higher incidence of lung cancer. The conclusion was obvious: Lung cancer was caused by sugar. But did the facts really support this conclusion? Was there an alternative explanation?

A careful re-examination of the patients showed that the line between cause and effect in this experiment had been improperly drawn. It turned out that the high-sugar group contained a higher percentage of smokers. Careful re-examination of the study suggested that the real link was between smoking and lung cancer, a fact now supported by more than 40 additional studies. Incidentally, this example illustrates a key principle of critical thinking: *Correlation doesn't necessarily mean causation*.

Numerous additional examples are available for classroom discovery. In 1989, for example, doctors found that many patients taking large doses of L-tryptophan (an amino acid) were becoming ill. L-tryptophan is taken by some to help them to get to sleep and by others to ease symptoms of premenstrual syndrome. Doctors reported more than 1200 cases of L-tryptophan "poisoning" to the Centers for Disease Control; more than a dozen people died. Many others were left nearly paralyzed or severely impaired. As a result, L-tryptophan was taken off the market. Headlines in newspapers proclaimed its dangers. Further research, however, suggests that the culprit was not L-tryptophan, but a chemical contaminant in the pills.

Fifth Principle: Look for hidden assumptions and bias. In many contemporary medical, environmental and social issues, proponents often offer data that supports their point of view while ignoring data that opposes it (violating the first principle). Sometimes the selective inclusion/exclusion of data is unconscious. Proponents simply seek out facts that support their view. That is, they make up their minds, then seek to prove their case with facts. This leads to the next principle of critical thinking—look for hidden assumptions and bias that often cause people to present distorted truth.

Excellent examples of this phenomenon can be found in books that portray the history of biological sciences. A few case studies presented in class will illustrate how preconceived notions and biases have distorted biological discoveries over the years. Two good sources are Gabriel and Fogel (1955) and Harre (1983).

Many contemporary examples of this phenomenon are also available. For instance, some individuals assert that all radiation exposure is dangerous and should, therefore, be avoided. This conclusion is based on the assumption that there is no threshold level for radiation—that is, a level below which radiation is harmless. If one accepts this conclusion, then it follows that all exposure is dangerous. Some scientists, however, assert that there is a threshold level, so low levels are not harmful.

As another example, some so-called health experts promote the use of megadoses of water-soluble vitamins. This advice is based on at least two underlying assumptions. The first one is that if a little vitamin is good for you, a lot must be even better. Second, and more prevalent, megadoses of water-soluble vitamins are safe because they are excreted in the urine. Nutritional research, however, has shown that large doses of water-soluble vitamins can cause significant harm (Christian & Gregor 1991; Hamilton, Whitney & Sizer 1991).

Sixth Principle: Question the source of the facts—that is, who is telling them. The principles of critical thinking presented here are interrelated. Questioning the conclusions of a study (fourth principle) requires us to question the methods (third principle) as well as the hidden biases and assumptions (fifth principle). It also means questioning the sources of facts (sixth principle) because proponents often have a hidden agenda and their views are tainted by bias, erroneous assumptions or incomplete information (first principle).

So-called industry experts, for example, are often biased by corporate goals. A drug company expert may announce that a new product is safe, but hidden biases may cloud that person's judgment. Experts from the environmental field may be swayed by a hidden agenda as well.

Seventh Principle: Don't expect all of the answers. Ironically, critical thinking requires a tolerance for ambiguity. Ambiguity exists in all fields of human study because of the tremendous lack of information in some areas and the complexity of many issues. Much to our own frustration, hard-and-fast answers are not always available. Sometimes it is necessary to wait and see. A good example of a place where uncertainty exists is the global warming debate. Many atmospheric scientists currently believe that the temperature of the Earth is warming as a result of excess carbon dioxide and other gases from human activities that have accumulated in the atmosphere over the past 100 years. Many prominent scientists are even willing to stake their reputations on it, and they quote an impressive body of information in support of their view.

Unfortunately for public policy makers, not all scientists agree. In fact, some believe that the conclusions of the colleagues on the other side of the issue may be wrong. Too many uncertainties exist to know for sure. Global warming may, therefore, be an issue where critical thinkers might reserve opinion. This leads us to the next principle of critical thinking.

Eighth Principle: Examine the big picture. Considering the high stakes of global warming, a dramatic shift in world climate that could turn productive farmland to desert, flood coastlines, extinct tens of thousands of species and make our lives more miserable, those who recognize that there is some uncertainty, might still choose to take action now. That is to say, although not all of the facts are in, the potential impact of greenhouse warming is so great that actions to halt the process are merited. A look at the bigger picture shows that reducing the threat of global warming can be brought about by improvements in use of energy in all sectors of society. Contrary to public misconception, these changes won't cost us money, they could very likely save our economy $200 billion or more while making substantial cuts in pollution (Rocky Mountain Institute 1991). Efforts to reduce global warming would have the added benefit of reducing other environmental problems like urban air pollution, acid deposition, habitat destruction, water pollution and others. It would stretch our limited supplies of oil and other fuels.

Consider another slightly different example of the benefits of examining the big picture. In 1988, researchers at Monsanto announced that they had found a way to alter the chromosomes of wheat to make the plant resistant to a fungus that causes enormous crop damage. To control the fungus now, farmers usually rotate wheat from year to year with other crops that do not support the pest. With the new genetically altered strain, say Monsanto spokespersons, farmers won't have to bother rotating crops. They can plant their fields in wheat year after year and can even plant larger crops without worrying about fungus infections.

While this may sound good, it is most likely a step that will create more problems than it solves. Ask your students to study the matter in more detail. You might have them begin by looking at the benefits of crop rotation. As they probe deeper, they will invariably find that crop rotation helps build soil fertility. Rotating beans, clover, alfalfa and other legumes with wheat, for example, adds nitrogen to the soil and helps to maintain soil fertility. Not rotating crops often drains a soil of its nutrients, reducing its productivity over time and requiring farmers to spend more money for fertilizers. Commercial fertilizers only replace three of the nutrients plants rob from the soil. Crop rotation also helps make substantial reductions in insect pest populations. By planting a new crop in a field every year, farmers reduce food sources for insects that tend to prefer one crop over another. Because the food supply is not constant from one year to the next, pest populations remain low and manageable. Eliminating crop rotation will very likely result in an outbreak of harmful wheat-eating insects, which will require costly pesticides that could contaminate groundwater and nearby lakes and streams, and could have adverse effects on birds and other animals.

Once your students have finished examining this issue, ask them to decide whether the research at Monsanto will help or hinder farming and the environment. You might also ask them how their study of the bigger picture altered their perception of the Monsanto announcement.

Ninth Principle: Examine multiple cause and effect. Be wary of simple answers and dualistic thinking. Critical thinking requires us to examine multiple cause and effect. This principle is really an extension of the last.

Humans often rely on rather simplistic thinking. In the 1970s, for example, one respected ecologist argued vigorously that the world's environmental problems resulted from overpopulation—too many people for the available resources. Another equally noteworthy scientist argued that the problems were due to technology and its byproducts—pollution.

A careful analysis shows that environmental problems are the result of many factors (Chiras 1980, Chiras 1992). Overpopulation, technology and per capita consumption also contribute to the environmental problems now facing the world's people. Inadequate laws and poor education must be factored into the equation along with various psychological factors such as the prevalent view of nature as a force to overcome. Many more could be added to the list.

Clearly, critical thinking demands a broader view of cause and effect. It calls on us to consider *all* of the contributing factors and their relative contributions. It warns against simplistic thinking.

As the population/technology debate illustrates, the most common form of simplistic thinking is dualistic thinking. Dualistic thinking encompasses only two viewpoints. It is black or white, right or wrong reasoning. Presenting a person with only two choices when there are many is technically called a false dichotomy. Such dualism should be a signal to a critical thinker to look deeper. When presented with two alternatives, look for a third or a fourth. They're often there, and they're often valid.

You can assist students by teaching them models of multiple cause and effect, which I have presented in several different publications (Chiras 1980, Chiras 1991). Take a simple problem they're interested in, present the common arguments, then ask students to dig deeper into the matter to uncover other contributing factors. After exploring a few issues in this manner students will become pluralistic thinkers.

Tenth Principle: Watch for thought stoppers. In analyzing issues—more, say, than the results of scientific research—it is important to be aware of thought stoppers, words or phrases that, while appealing, switch off the critical thinking faculties (Causey 1991). Thought stoppers elicit an emotional, or gut-level acceptance of an argument, not an intellectual one. As a rule, they work because they arouse emotions; they literally sound so good you lose tract of your thinking. Many thought stoppers repeat old myths.

When talking about individual actions to help protect the environment, for example, many people say to me, "So what, what effect do my actions have?" That's a thought stopper par excellence. It plays on our feelings of helplessness and insignificance. It's a hard one to answer, until, of course, you start thinking. Although individual actions don't amount to much, when added together, they can become meaningful. After all, many of our problems are the result of individual actions—carelessness and waste. If they create our problems, they can also be part of the solution (Chiras 1990).

Eleventh Principle: Understand your own biases and value. Critical thinking requires careful analysis, but many people forget that to be a critical thinker we must scrutinize our own positions and statements as carefully as we examine those of others. Each of us has a set of values and ideas about the way the world works, some of which can be quite erroneous. Our values and ideas influence our own reasoning. Surprising as it may seem, one useful exercise, especially in classroom discussions of environmental issues, is to clarify your own values and preconceived notions.

Much To Lose/Everything To Gain

At this juncture in history, technology and scientific knowledge abound, impacts to the environment are becoming far more pronounced, and human political interactions are as complex as ever. Because of these and other forces at work today, students can no longer be armed with a brainful of facts and then be set loose to make their way through the societal maze. To function optimally in a complex world they must learn to think critically. Science teachers can play a significant role in this process. Not providing skills of critical thinking is simply too costly at this juncture in our cultural evolution. The stakes are too high for us to continue to turn out students whose critical thinking skills are sorely underdeveloped. By helping our students develop this important intellectual skill, we have much to gain.

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