Assessing Toxic Risk

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Cornell Scientific Inquiry Series
Teacher’s Guide

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INTRODUCTION

ENVIRONMENTAL INQUIRY

Assessing Toxic Risk is part of the Environmental Inquiry (EI) curriculum series developed at Cornell University to enable high school students to conduct authentic environmental science research. The goals of EI are for students to

1. Develop research skills
2. Use their newly acquired skills to conduct research projects of their own design focusing on topics relevant to their local communities
3. Participate in communities of peer student scientists
4. Enhance their understanding of scientific content and process

Rather than learning science as a static body of facts, EI students experience the research process through which scientific understandings are formed and continually revised. Instead of memorizing a “scientific method,” they discover for themselves the multifaceted nature of scientific research. By studying problems relevant to their communities, they discover interconnections between science and society.

MEETING THE STANDARDS

The contemporary movement for science education reform calls for the teaching of science to more closely reflect the way in which science is practiced. According to the National Science Education Standards (National Research Council, 1996), the central strategy for teaching science should be to engage students in authentic inquiry or research:

Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with the processes of inquiry, including asking questions, planning and conducting an investigation, using appropriate tools and techniques, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments.

(NRC 1996, 105)

The Science as Inquiry Standards call for all students to develop the following abilities:

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations
- Use technology and mathematics to improve investigations and communications
- Formulate and revise scientific explanations and models using logic and evidence
Recognize and analyze alternative explanations and models
Communicate and defend a scientific argument (NRC 1996, 175–6)

Using a stepwise approach, EI research helps students gain all of these abilities as they design and carry out investigations, exchange ideas about their results and interpretations with peer student scientists, and make recommendations for future experiments. A progression of worksheets guides students through each step of the inquiry process, providing structure but flexibility in designing and conducting meaningful projects.

Students engaged in EI toxicology research also will learn concepts and skills covered in other Standards, including Science in Personal and Social Perspectives; History and Nature of Science; and several other fields (Table 1).

AUDIENCE
Assessing Toxic Risk can be used as a module in biology, chemistry, environmental science, and general science courses, or as a resource for individual student research projects. The background text and research techniques have been successfully used in courses ranging from 8th grade through advanced placement science, with adaptations in the level of sophistication expected in experimental design, and interpretation and presentation of results.

In a growing number of schools, integrated science or environmental science is taught as an introductory or basic-level high school science course. Assessing Toxic Risk works well in this setting because it does not assume detailed prior knowledge of any of the science disciplines and is based on thought-provoking hands-on activities.

By incorporating critical thinking, communication, and technology skills, the EI curriculum helps all types of students to succeed in science. Although research experiences commonly are reserved for advanced students, the EI curriculum series is designed to extend these opportunities to all students, including those who have not flourished in more traditional “college-preparatory” science courses. EI pilot testing has shown that students who are not accustomed to thinking of themselves as scientists gain motivation and self-esteem when faced with the challenge of carrying out authentic research projects and then reporting their results and exchanging critiques with other students.

For more advanced science classes, Assessing Toxic Risk provides opportunities to expand students’ understanding of complex concepts related to toxicology, risk analysis, and the nature of conducting scientific research. Many possibilities exist for cross-curricular collaboration, for example, by linking scientific studies of toxicology with discussions of environmental policy, history, and law.
### TABLE 1
NSES Content Standards Addressed through EI Toxicology Research

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Unifying Concepts and Processes in Science</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Systems, order, and organization</td>
<td></td>
</tr>
<tr>
<td>Evidence, models, and explanation</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Change, constancy, and measurement</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Evolution and equilibrium</td>
<td></td>
</tr>
<tr>
<td>Science as Inquiry</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Abilities necessary to do scientific inquiry</td>
<td></td>
</tr>
<tr>
<td>Understandings about scientific inquiry</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Physical Science</td>
<td></td>
</tr>
<tr>
<td>Chemical reactions</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Life Science</td>
<td></td>
</tr>
<tr>
<td>Molecular basis of heredity</td>
<td></td>
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<tr>
<td>Biological evolution</td>
<td></td>
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<tr>
<td>Interdependence of organisms</td>
<td></td>
</tr>
<tr>
<td>Behavior of organisms</td>
<td></td>
</tr>
<tr>
<td>Science and Technology</td>
<td></td>
</tr>
<tr>
<td>Understandings about science and technology</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Science in Personal and Social Perspectives</td>
<td></td>
</tr>
<tr>
<td>Personal and community health</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Population growth</td>
<td>● ● ● ● ● ●</td>
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<tr>
<td>Natural resources</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Environmental quality</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Natural and human-induced hazards</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Science and technology in local, national, and global challenges</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>History and Nature of Science</td>
<td></td>
</tr>
<tr>
<td>Science as a human endeavor</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Nature of scientific knowledge</td>
<td>● ● ● ● ● ●</td>
</tr>
<tr>
<td>Historical perspectives</td>
<td>● ● ● ● ● ●</td>
</tr>
</tbody>
</table>
WHY TOXICOLOGY?

RELEVANCE
One of the reasons for studying toxicology at the high school level is its relevance to everyday life. On a daily basis we are confronted with news reports about toxic chemicals in our food, water, and environment. How do we decide which of these are worth worrying about? Each of us must make individual decisions about questions such as, “Should I buy bottled water, or is it safe to drink water from the tap?” We also can exert political pressure to influence broader societal questions such as, “Should the federal government ban sales of saccharin?” or “Should the town spray herbicides to control weed growth along the highways?” Too often these decisions are based on misconceptions about what is “safe” and what involves too great a risk. In learning the basic concepts of toxicology, students will become better prepared to make reasoned decisions about issues such as these.

Toxicology research offers the opportunity to connect classroom science to relevant issues in all types of communities—urban, suburban, and rural. For example, students in Ithaca, New York, carried out experiments to compare the toxicity of road salt (sodium chloride) with deicing alternatives such as magnesium chloride, calcium chloride, and an “environmentally friendly” product made from food-processing wastes. They sent their results to the local highway department, which had been pilot testing alternative deicing techniques. According to their teacher, “Having this sort of community connection helps students to see that scientific research has real-world applications and is not just something that scientists carry out in isolation in their labs.”

CONNECTIONS
Toxicology provides a natural link between scientific disciplines, including biology, chemistry, environmental science, and human health. School sciences often are presented as discrete fields with few interconnections. By highlighting the natural links among these fields, toxicology can make science more interesting and relevant to high school students.

The study of toxicology also highlights the connections between science and public policy. For example, when students interpret the results of their toxicology experiments, they can better understand the interplay between scientific data and human judgment underlying public policy decisions such as the setting of standards for drinking water quality.
WHY TOXICOLOGY?

RESEARCH OPPORTUNITIES
One of the great challenges for science teachers is to provide students with opportunities to conduct authentic open-ended investigations that are safe and feasible to perform at the high school level. Bioassays, in which organisms are used to evaluate the toxicity of chemicals, are ideally suited to student research. Not only are bioassays simple and inexpensive to carry out, they also are authentic techniques used by professional scientists.

Using lettuce seeds, duckweed, and/or Daphnia, students can carry out the same types of toxicity tests used by scientists in universities, government, and industry. Although these scientists have access to budgets and equipment far beyond the realm of high school laboratories, they still use bioassays to provide an integrated picture of toxicity. For example, bioassays are used to map areas for cleanup of contaminated sites, and to determine whether effluent from wastewater treatment plants, industries, or landfills is clean enough to be discharged into a stream or lake. With very few modifications, students can carry out the same procedures to answer questions relevant to their own communities.

Like many scientific experiments, bioassays often lead to more questions than they answer. After each experiment, students are likely to come up with several more questions that could be addressed through further experimentation. Given the time and freedom to carry through with some of these ideas, students will be able to experience firsthand the creativity inherent in research and the excitement of practicing scientific inquiry.

CRITICAL THINKING
Too often, students view scientific work as a set of exercises with only one right answer or result. This leads to confusion when scientists publicly disagree about contentious issues such as global warming, food safety, or causes of cancer. How can both sides of the argument be scientific? Once students have had the experience of carrying out their own research, they will better understand the mixture of analytic and subjective decisions that sometimes lead to conflicting conclusions within the scientific community. By looking at their own and other students’ data, they will begin to see how bias can affect everything from methods to interpretation of results.

When interpreting the results of their bioassay experiments, students will find that they need to think carefully about what conclusions are justified. If duckweed and Daphnia thrive in samples of lake water, would it be reasonable to conclude that it is safe for humans to swim in this water or even to drink it? Of course not, since human physiology is significantly different than that of the bioassay organisms. So what does it mean to say that a chemical is toxic? What is reasonable to conclude from bioassays in terms of the toxicity to the test organisms and to other species, possibly including humans?

In grappling with questions such as these, students are forced to identify their assumptions and to think critically about various explanations of their results. Initially they may jump to conclusions but then realize through classroom discussions and reviewing their work that other interpretations are possible or that further experiments are needed before a final conclusion can be reached. (See Interpreting the Results, p. 33, for further discussion of these issues.) This is similar to the process that professional scientists go through in interpreting and presenting their research results.

In sum, students using Assessing Toxic Risk will learn concepts inherent to the study of toxicology and to conducting scientific research through engaging in real-life experiments.
relevant to their communities. Table 2 lists intended learning outcomes for students engaged in EI toxicology research.

**TABLE 2**

**Intended Learning Outcomes**

<table>
<thead>
<tr>
<th>Skills: Students will be able to</th>
<th>Concepts: Students will understand that</th>
</tr>
</thead>
<tbody>
<tr>
<td>◗ Conduct scientific research, starting with well-defined protocols and progressing to open-ended research projects</td>
<td>◗ Toxicology is the study of harmful effects of chemicals on living things</td>
</tr>
<tr>
<td>◗ Work collaboratively to design experiments, interpret results, and critically analyze ideas and conclusions</td>
<td>◗ Toxicology involves interactions between biology, chemistry, environmental science, and human health</td>
</tr>
<tr>
<td>◗ Define a toxicological research question, then plan and carry out an experiment to address this question using bioassays with one or more types of organism</td>
<td>◗ Dose/response bioassays provide a measure of toxicity</td>
</tr>
<tr>
<td>◗ Analyze data and draw conclusions about toxicity and risk</td>
<td>◗ Chemical risks are relative, and every chemical is toxic at a high-enough dose</td>
</tr>
<tr>
<td>◗ Identify sources of variability in data, including potential sources of bias</td>
<td>◗ There is no such thing as “zero risk.” Setting environmental standards requires both scientific data and human judgment to determine what level of risk is acceptable to society</td>
</tr>
<tr>
<td>◗ Write a concise and accurate summary of methods, results, and conclusions</td>
<td>◗ Science is multidisciplinary and related to societal concerns</td>
</tr>
<tr>
<td>◗ Use commentary from fellow students to revise or justify research reports and presentations</td>
<td>◗ Clear presentation of research results is an integral part of the scientific process</td>
</tr>
<tr>
<td>◗ Critically analyze summaries of other students’ research to determine whether each study was based on good experimental design</td>
<td>◗ Scientists work both individually and collaboratively, reviewing each other’s work to provide feedback on experimental design and interpretation of results. These “peer reviews” are used to make decisions about what research gets funded and what results get published in scientific journals</td>
</tr>
<tr>
<td>◗ Provide constructive criticism of fellow students’ data analysis, interpretations, and conclusions</td>
<td>◗ Scientific understandings are tentative, subject to change with new discoveries. Presentation and peer review of research results are key aspects of the process through which scientists sort genuine discoveries from incomplete or faulty work</td>
</tr>
</tbody>
</table>