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Cornell Scientific Inquiry Series

TEACHER EDITION

Decay and Renewal

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INTRODUCTION

ENVIRONMENTAL INQUIRY

Decay and Renewal 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, 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 investigations, using appropriate tools and techniques to gather data, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments.[1]

The Science as Inquiry standards[2] 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

[1]National Research Council (NRC). 1996. *National Science Education Standards.* Washington, DC: National Academy Press, p. 105.

[2]NRC, pp. 175–6.

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- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument

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 *Decay and Renewal* projects also will learn concepts and skills covered in other standards, including Life Science, Physical Science, Science in Personal and Social Perspectives, and several other fields (Table 1).

AUDIENCE

Decay and Renewal 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 eighth 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. *Decay and Renewal* 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. 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 feedback with other students.

For more advanced science classes, *Decay and Renewal* provides opportunities to expand students' understanding of complex concepts related to the interdependency between organisms and the environment and the complex interrelationships among chemical, biological, and physical processes inherent in nutrient cycling and energy flow through ecosystems.

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TABLE 1
National Science Education Content Standards Addressed through EI Research

National Science Education Standards (National Research Council, 1996)	Addressed in *Decay and Renewal*: Chapters 1 – 3	Protocols 1 – 4: Collecting Invertebrates	Protocols 5 – 7: Culturing Microbes	Protocols 8 – 11: Chemical Effects	Protocol 12: Composting & Landfilling	Protocol 13&14: Bioremediation	Interactive Research	Design Challenge
Unifying Concepts and Processes in Science								
Systems, order, and organization	●	●	●	●	●	●	●	
Evidence, models, and explanation				●	●	●	●	●
Change, constancy, and measurement	●		●	●	●	●	●	●
Evolution and equilibrium					●	●	●	
Science as Inquiry								
Abilities necessary to do scientific inquiry		●	●	●	●	●	●	●
Understandings about scientific inquiry		●	●	●	●	●	●	●
Physical Science								
Structure and properties of matter				●		●	●	
Chemical reactions	●			●	●	●	●	●
Conservation of energy and increase in disorder	●						●	
Interactions of energy and matter	●					●	●	
Life Science								
The cell	●		●	●		●	●	●
Biological evolution	●					●	●	
Interdependence of organisms	●	●	●	●	●	●	●	●
Matter, energy, and organization in living systems	●			●	●	●	●	●
Behavior of organisms		●	●	●		●	●	
Earth and Space Science								
Geochemical cycles	●			●				
Science and Technology								
Understandings about science and technology	●			●	●	●	●	●
Science in Personal and Social Perspectives								
Population growth								●
Natural resources	●			●	●	●	●	●
Environmental quality	●	●	●	●	●	●	●	●
Natural and human-induced hazards	●			●	●	●	●	●
Science and technology in local, national, and global challenges	●			●	●	●	●	●
History and Nature of Science								
Science as a human endeavor		●	●	●	●	●	●	●
Nature of scientific knowledge		●	●	●	●	●	●	●
Historical perspectives	●			●	●	●	●	●

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WHY BIODEGRADATION?

Decay and Renewal presents inquiry-based approaches to studying biodegradation, the assortment of biological processes that cause organic matter to decay. Biodegradation occurs in nature and in human-engineered systems to prevent or clean up environmental contamination. Why study biodegradation? Because it provides a wealth of opportunities for students to learn basic biological and ecological concepts while engaging in investigations about environmental issues of relevance in their everyday lives.

RELEVANCE

When we throw or flush something away, we don't often stop to think about where it is going and what will become of it. In the big picture, of course, there is no "away." Some substances break down and others don't, and either way leads to environmental consequences. Through investigation of the processes inherent in wastewater treatment, composting, landfilling, and bioremediation of contaminated sites, students learn important science concepts within the context of issues that relate to protection and enhancement of environmental quality.

CONNECTIONS

Although high school science courses commonly cover issues related to water quality, wastewater treatment, solid waste management, and pollution prevention, students do not always recognize the connections between these topics. By exploring the ways in which all of these processes make use of the natural forces of decay and renewal, students will gain a greater conceptual understanding of the science underlying these important issues.

Students who carry out biodegradation experiments also experience the links among scientific disciplines. For example, composting, wastewater treatment, and bioremediation may seem to be primarily biological processes. However, for optimal performance, all of these processes rely heavily on chemical and physical properties. By highlighting the natural links among scientific disciplines, and their inherent connections to applied technologies, biodegradation research and engineering design experiences can help students to gain a more integrated view of science and its applications to issues of concern to society.

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OPPORTUNITIES FOR RESEARCH AND ENGINEERING DESIGN

Decay and Renewal is designed to help schools meet the challenge of giving students authentic and meaningful research experiences within the ever-present constraints of time and resources. Biodegradation provides an ideal topic for student research and engineering design projects that focus on issues of genuine societal concern. Study of biodegradation leads to a wide range of questions related to how organic materials break down in nature or in composting, wastewater treatment, or bioremediation systems. Based on questions of their own design, students can use one or more of the protocols in this manual to conduct feasible classroom experiments.

In addition to carrying out research projects, students using *Decay and Renewal* will learn basic concepts of nutrient cycling, energy flow, respiration, and biodegradation. As they conduct their investigations, students will draw on their understanding of scientific concepts from a variety of disciplines. For example, composting research enables students to learn about biological, chemical, and physical processes such as uptake of carbon and nitrogen by microorganisms, diffusion of oxygen through air and water, and effect of moisture on heat production and transfer. Similarly, wastewater treatment involves vital interconnections among biological, chemical, and physical processes working together in the decomposition of organic wastes.

CRITICAL THINKING

"Plants photosynthesize and animals respire." "Plants get their food from the soil." "All bacteria are harmful." These common misconceptions affect student understandings about basic biological and ecological processes such as photosynthesis, respiration, nutrient cycling, and energy flow. Students can tackle their misconceptions by designing experiments that will test their understandings. Do plants produce CO_2, or just use it? What are the critical factors for plant growth? Will composting or wastewater treatment systems function without bacteria?

Sometimes students come up with unexpected results, and their first response is to assume that the data are incorrect, and so they must have done something wrong. However, this may not be the case, and tracking down the source of the discrepant results provides an ideal opportunity for critical thinking and in-depth analysis. Maybe something did go wrong with the experiment, but another possibility is that the initial expectations were incorrect. Classroom discussions and library and Internet research may help to sort this out. If there is time for follow-up experiments, they can be used to test newly generated predictions about the expected outcomes.

Table 2 lists intended learning outcomes for students engaged in EI biodegradation research and technological design.

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TABLE 2
Intended Learning Outcomes

Skills: Students will gain the ability to

- Conduct scientific research, starting with well-defined protocols and progressing to open-ended research projects
- Define a biodegradation research question, then plan and carry out an experiment to address this question
- Engage in engineering design, including planning, constructing and testing a device, assessing cost, and then presenting and critiquing the results with fellow students
- Work collaboratively to design experiments or engineering designs, interpret results, and critically analyze ideas and conclusions
- Analyze data and draw conclusions about the research or design results
- Write a concise and accurate summary of methods, results, and conclusions
- Engage in peer review to exchange constructive criticism of data analysis, interpretations, and conclusions
- Use feedback from fellow students to revise or justify reports and presentations

Concepts: Students will gain the understanding that

- Life on Earth depends on cycling of carbon and other nutrients, and on flow of energy from the Sun to producers, consumers, and decomposers
- Bacteria and fungi play essential roles in nutrient cycling and energy flow on land and in water
- Decomposers play crucial but often hidden roles in food webs and energy pyramids
- Through photosynthesis, producers use solar energy, CO_2, and water to create food in the form of chemical energy. Consumers, including decomposers, obtain energy by eating other organisms or their wastes
- Through cellular respiration, living things use the chemical energy stored in organic compounds, releasing CO_2, water, and heat as by-products
- Humans harness natural forces of decay in order to protect or clean up the environment through composting, wastewater treatment, and bioremediation
- Science is multidisciplinary and relevant to societal concerns
- Scientists and engineers work both individually and collaboratively, reviewing each other's work to provide feedback on experimental design and interpretation of results
- Scientific understandings are tentative, subject to change with new discoveries. Peer review among scientists helps to sort genuine discoveries from incomplete or faulty work

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LEVELS OF INQUIRY

Environmental Inquiry (EI) is organized into two levels of inquiry modeled after research activities conducted by professional scientists. Students first learn standard research methods, or protocols. Then they explore possibilities for using these protocols to address relevant research or technological design questions. After planning and carrying out one or more interactive research experiments or engineering designs, students present and discuss the results with their peers and possibly with interested community groups.

EI research represents a continuum, with progressively increasing levels of student responsibility for the design of the investigations. There also is a progression in interaction among students as they learn to critically analyze their results, argue among alternative interpretations, and communicate their findings to fellow student scientists (see Figure 1).

GUIDING PROTOCOL-LEVEL INQUIRY

EI protocols introduce students to standard laboratory and field methods that have been adapted from university research to be feasible and safe for use by high school students. Experience with the protocols helps students to develop basic skills and understandings they will be able to use in designing and carrying out scientific investigations.

Protocols differ from traditional school laboratory exercises because they are research techniques rather than demonstrations, so the teacher does not necessarily know the outcome in advance. The **Data Forms** included in the *Student Edition* will guide students through the appropriate steps in data analysis and interpretation, including the final step of generating ideas for follow-up experiments.

Although at this level the students may not develop their own plan of work, it still is important for them to recognize what the research question is and how this question relates to the work they will be carrying out. The **Protocol Planning Form** (p. 96) should help them to make these connections.

Collaborative work is integral to EI research, including at the protocol level (Table 3). This collaboration includes the process of peer review, through which students exchange feedback about their work. Although peer review is used primarily at the interactive research level, students who have completed a protocol can critique each other's results and conclusions and exchange written feedback using the **Data Analysis Peer Review Form** (p. 97). This step introduces students to the benefits of exchanging constructive criticism, both to sharpen their own thinking and to provide advice to their peers.

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FIGURE 1
Levels of Inquiry in EI

NOTE: Many different sequences are possible, depending on student ability levels and interests as well as considerations of time and curriculum.

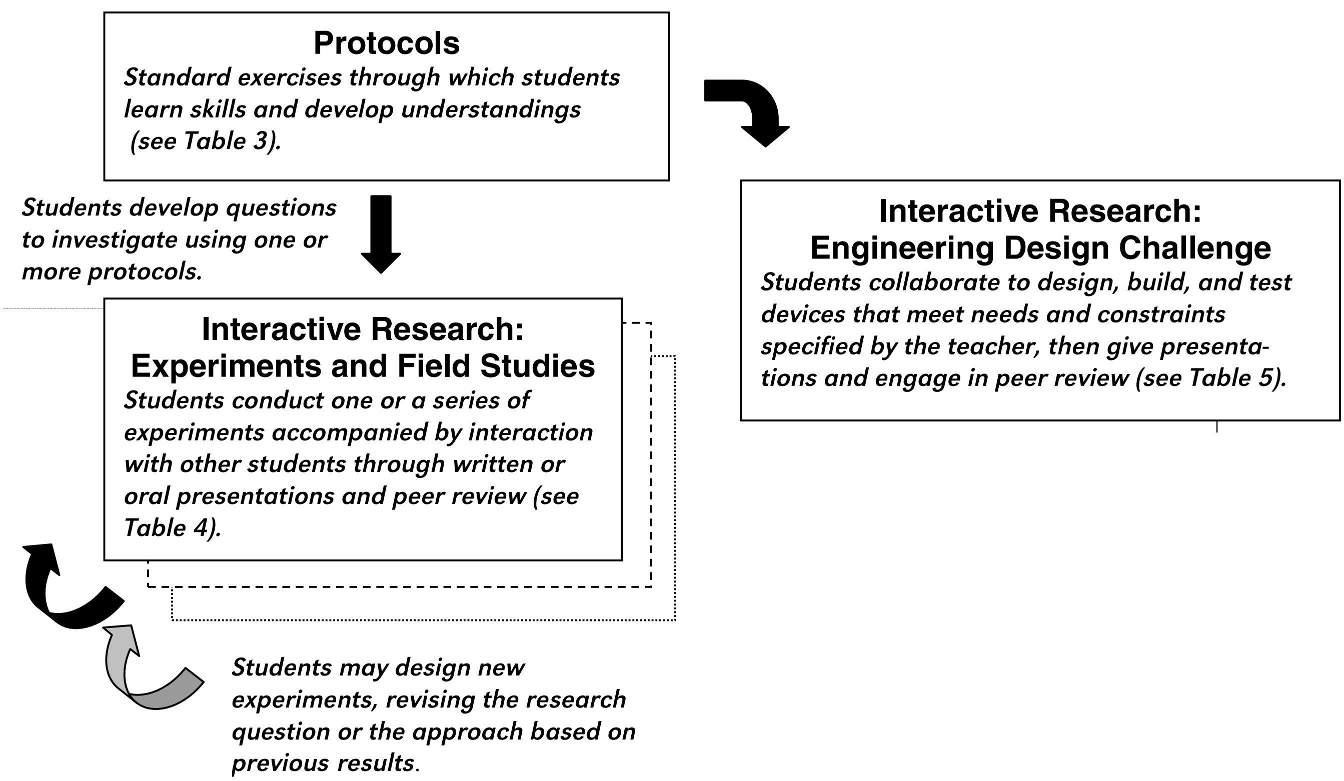

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TABLE 3
Steps in Carrying Out an EI Protocol

Activity	Collaborative and Individual Work	Peer Review Process
Planning to use a protocol	Students work individually or collaboratively to fill out the **Protocol Planning Form** (p. 96).	N.A.
Carrying out a protocol	Students work in groups to conduct a protocol.	N.A.
Analyzing and presenting the results	Students work individually or collaboratively to report and analyze their data, then write individual lab reports.	Before students write their reports, groups pair up to discuss and compare results using the **Data Analysis Peer Review Form** (p. 97).

CONDUCTING INTERACTIVE RESEARCH

Having mastered one or more of the protocols, students use these techniques to carry out open-ended research or technological design projects. This level is called interactive research because it emphasizes collaborative knowledge building and information exchange. Through these collaborative interactions, students not only improve their own work and enhance their critical thinking skills, they also model an essential process underlying all professional scientific communities.

One of the goals of interactive research is to dispel the common misconception among students that science is a career that is pursued in isolation. Students commonly do not realize the extent to which scientists work together to discuss ideas, share findings, give each other feedback, and collaborate on joint projects. Scientists also communicate with larger, non-science communities. Scientific findings inform public decision-making, and, in turn, community priorities help shape scientific research agendas.

Experiments and Field Studies

At the interactive research level, students work in groups to plan and conduct experiments or field studies (Table 4), then communicate their findings and build on each other's experiences as they carry out the following processes:

- Narrowing down an interesting research question
- Planning an appropriate experiment or series of experiments
- Sharing observations and advice with other students who are conducting similar studies
- Discussing various possible interpretations of research results
- Presenting findings in oral or written form
- Participating in peer review of research presentations
- Recommending ideas and approaches for future experiments

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TABLE 4
Collaboration and Peer Review in Experiments and Field Studies

Activity	Collaborative Work	Peer Review Process
Planning an experiment	Students work together to brainstorm research ideas, then fill out **Choosing a Research Topic** (p. 110) and **Interactive Research Planning Form #1** or **#2** (pp. 113 and 115).	Student groups are paired up to discuss and refine research plans using the **Experimental Design Peer Review Form** (p. 124).
Carrying out the experiment	Students work in groups to conduct experiments.	N.A.
Analyzing and presenting the results	Students collaborate to analyze their data, then write research reports using the **Research Report Form** (p. 120) or create posters using the **Poster Guidelines** (p. 123).	Students present their research results, then exchange feedback using the **Research Report Peer Review Form** (p. 125) or **Poster Peer Review Form** (p. 126). Final reports incorporate changes generated through peer review.

Wastewater Treatment Design Challenge

A second form of interactive research is the design challenge, in which students apply skills in mathematical analysis, scientific inquiry, and technological design toward solving a specified problem within certain constraints. Design challenges differ from experiments in that the teacher specifies a specific problem for the students to address. Working with the provided specifications, students select, build, and test a design they have chosen to be optimal in balancing performance with cost. After demonstrating their devices, student teams assess the performance, cost, and strengths and weaknesses of each. This process is included in interactive research because the students demonstrate their devices publicly and share in the process of peer review (see Table 5).

In *Decay and Renewal,* students are challenged to plan and build devices to treat simulated wastewater. This challenge provides an engaging way for students to apply what they have learned about the science of biodegradation while working to solve a problem of genuine relevance. Student teams define the problem, identify alternative solutions, and select their best design based on consideration of factors including cost, safety, and anticipated effectiveness. After building, testing, and refining their devices, students give presentations and evaluate each other's work using the **Design Challenge Peer Review Form** (p. 140).

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TABLE 5
Collaboration and Peer Review in a Design Challenge

Activity	Collaborative Work	Peer Review Process
Designing alternatives and choosing the best alternative	In response to a teacher-specified design problem, students work in groups to brainstorm ideas and then choose the best alternative using the **Design Selection Rubric** (p. 137) and present it to the teacher using the **Design Proposal Form** (p. 138).	N.A.
Building and using a device	Students work in groups to build, test, refine, and then run a wastewater treatment unit.	N.A.
Analyzing and presenting the results	Students collaborate to evaluate the effectiveness of their device and to plan a presentation of their work.	Students demonstrate their device and their assessment of its performance, then exchange feedback using the **Design Challenge Peer Review Form** (p. 140).