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There’s More to Teaching Science

By Doug Ronsberg

Doug Ronsberg is a special education paraprofessional for grades two and three at Castle Elementary in Oakdale, Minnesota.
There's more to teaching science than stuffing kids with facts—
cause unconnected data flow like rain right off their backs.
Help kids discover nature, stars and waves, and tracks,
dinosaurs, and temperature, and killer bee attacks.

They have to learn to question, to observe, and to explore—
to seek the basic causes, to measure, count, and more.
So shelve that fault-line lecture; it'll bore them to the core.
Active kid engagement is the key to learning's door.

Kids need to think like scientists, to sort and sift and muse;
to evaluate the evidence—conclude what they should use;
to see the laws of science through a range of different views;
and find their way around the lab, to search for proper clues.

Encourage novel thinking, new approaches, different ways—
creative problem solving fosters hope for future days.
Emphasis on science terms and jargon doesn’t pay;
clarify their thinking and the elements will stay.

Don't be the only fossil that your students learn about;
make your methods fit their needs and reassure throughout.
Give lots of time with science tools to ease their fear and doubt;
show women and minorities in science news you tout.

Cut down on competition and you'll help your students grow;
use learning teams to multiply the science seeds you sow.
Encourage interactions so they share the things they know—
to reason and defend the things they think their data show.

The adage about "Rocket Science" shouldn't conjure fear;
rocket science can be fun and you should make it clear—
that everyone contributes to the learning of each peer,
and they need not all aspire to "Rocket Engineer."

Don't preach on relativity—don't be an emcee square,
'cause you're not Albert Einstein and they really couldn't care.
Energize your classroom by getting kids to dare—
to gather, sort and catalog, and theorize, and share.

History's a matter that requires your energy;
a solid link between world and technology.
Insist on clear expression, not gaseous lethargy;
to make their learning liquid—and sound as it can be.

Yes, there's more to teaching science than stuffing kids with facts;
you must make them feel comfortable and help them to relax.
If the action just intimidates you know how they'll react;
they'll lose their own inertia, and be forced between the cracks.

So be the supernova within their galaxy;
courage scientific minds and you will set them free—
to love the world of science and almost guarantee—
why not, one day they could become Nobel nominees!
Introduction

Quite often during the summer, my wife and I take our children on walks in the bluffs along the upper Mississippi River. They dart back and forth, flipping over rocks and branches, looking for salamanders, bugs, and snakes. Occasionally, they will slip an interesting rock into a pocket or find the perfect walking stick (more likely, a poke-your-sibling stick). The woods ring with the sound of laughter and a never-ending stream of questions. Usually, one of them has started a new question before we have a chance to answer the first. Children love exploring. The opening line of Doug Ronsberg’s poem is the perfect way to begin this book: “There’s more to teaching science than stuffing kids with facts…” Science is about questions and exploration. Teaching science is about helping students ask questions and explore and explain the world around them.

Ronsberg continues, “Encourage novel thinking, new approaches, different ways—/creative problem solving fosters hope for future days.” Former NSTA President Harold Pratt recently wrote that good science teaching at the elementary level is critical to a child’s future. Poorly presented science can deaden children’s curiosity and lessen their wonder about the world around them. Students should be engaged “not only in the practice of science, but also the passion. Finding ways to ignite the curiosity and develop inquiring habits of mind is most important…” (2007). The purpose of this book is to provide a comprehensive compilation of practical examples and strategies for good science teaching, set in theoretical frameworks that support student learning. The book is divided into five sections that cover many aspects of teaching. Each section includes reflection questions and action steps that you can follow to deepen your understanding of the concepts presented.

Section 1 introduces you to how scientific knowledge is created. The section also describes a teaching approach—science inquiry—that provides a classroom model of how science is done. A selection of articles provides strategies to support student understanding of science and ability to conduct science inquiry.
Introduction

Section 2 looks at teaching science through four lenses. The learner-centered lens focuses on student engagement and initial knowledge. A knowledge-centered lens focuses on what content students should learn and how they should learn it. An assessment-centered lens focuses on using assessment to inform instruction and enable learning instead of just summative assessment. A community-centered lens focuses on creating an environment that supports discussion and risk taking.

Section 3 describes teaching that supports learning by students from all backgrounds.

Section 4 provides a toolbox of strategies that are important to good teaching: supporting literacy, integrating other disciplines, integrating technology, and teaching preschool and kindergarten students.

Section 5 describes the content of science by providing an overview of the content standards from the National Science Education Standards.

To kick off this book, I thought it would be appropriate to include the article “Inquiring Minds Do Want to Know” by Kaitlyn Hood and Jack A. Gerlovich. The article describes the experience of a preservice elementary teacher in an undergraduate science methods class as she engages fifth-grade students in scientific discovery. Hood describes the importance of this approach when she writes, “Perhaps more than anything else it changed the classroom atmosphere from presentation to discovery and application. I was no longer just a performer—I was someone who knew what the students could do and gave them a stage on which to perform.”

My hope is that this compilation will help you to create a classroom that encourages creativity and promotes exploration, a classroom that rings with the sound of laughter and a never-ending stream of questions.

Eric Brunsell
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Department of Educational Studies
University of Wisconsin—La Crosse

Reference
My first foray into inquiry science came a few years ago as part of an undergraduate science methods class at Drake University. In the class, groups of my colleagues were assigned to teach a four- to six-part lesson to students at various local elementary schools. The fifth-grade class to which my group was assigned was interested in tornadoes, so we decided to present a series of lessons that gave students a solid background for understanding how a tornado is formed. We visited the class six times, each time demonstrating a different aspect of tornadoes and how they affect people. (See Figure 1 for a day-by-day description of each visit’s lesson plan.)

I chose to lead the group’s fifth lesson. I wanted a lesson that went beyond the tornado in a bottle. I envisioned students making a tornado in the classroom so they could really see it working. I wanted the tornado to be close enough and safe enough for them to touch and perhaps even alter to make it taller, wider, or faster. Creating the tornado would be the students’ experiment—not the teacher’s. Although the idea was good, I had struggled to put together a lesson plan and turned to my professor for help.

As I discussed what I wanted to do in the class, we wondered what would happen if I told the students, “We now know about the conditions necessary for a tornado to form; let’s figure out how to make one in our classroom.” This form of teaching—in which the teacher poses the question but lets the students decide how to answer the question—falls into the guided-inquiry approach (Martin-Hansen 2002). It was an approach I was eager to try.

**Trying the Tornado**

The idea to have students create a tornado in class made my mind race. Being a preservice teacher, I didn’t have a lot of experience with students—and I did not see myself going into the classroom without knowing exactly what was going to happen. What would happen if students could not create the tornado? Would the students see us—their teachers—as failures? Or worse, would they think they themselves had failed? I knew enough about inquiry-based learning to know that some-
Inquiring Minds Do Want to Know

**Figure 1.**
Breakdown of tornado lessons

**Day One: Informal Preassessment**
This was a chance for the students to get to know their new teachers, as well as an opportunity for the teachers to find out what the students knew about tornadoes.

**Day Two: Introduction to Tornadoes**
The lesson started with the students returning from “specials” to find their classroom hit by a tornado. As the class put the desks and other classroom materials back in order there was a discussion on how a tornado can affect someone very personally. We then read two short accounts of tornado victims to enforce the idea of tornadoes being amazing forces of nature but also something that can affect someone’s life. We ended the class by introducing the idea of how tornadoes are formed by using bottle tornadoes as visual aids.

**Day Three: Panel of Experts**
We came into the classroom in costumes—we had a child who had lived through a tornado, a farmer, a tornado chaser, a weather forecaster, and a relief worker. We each gave the students a short talk on what we do when a tornado forms, and what kinds of things each expert finds really important. At the end of this lesson we gave them a worksheet to review the main points of the lesson and to keep in their science journals for future reference.

**Day Four: Science Safety**
The class had already discussed the basic ideas of how to be a safe scientist, so we decided to focus more on having each student sign a safety contract. Two of us dressed up as Science Safety Agents and explained what we expected from them as scientists. At the end of class we told the students that we wanted them to try to make a tornado next time we came and compiled a list of materials they requested.

**Day Five: Making a Tornado**
We brought in the materials, divided into groups, and let the students work through their ideas twice. The only assistance we gave them was when we handled the dry ice.

**Day Six: Assessment**
The class was divided into two groups. Different tornado and science safety facts that had been discussed throughout our classes were the basis of the review game questions. Each team worked together to formulate their answers and really knew their material.

times the process is more important than the product. Wittrock and Barrow (2000) said that the teacher is more of a facilitator when teaching with inquiry, but, when I thought about that idea in a real-life scenario, it scared me to death. Still, I forged ahead and created a plan for the lesson by reviewing the research we had discussed in class and writing a rough time line. I tried to run through various scenarios and troubleshoot any roadblocks we might encounter.

Two days later I presented the challenge to students in the classroom at our fifth visit. Students were primed for the challenge, because, at the conclusion of the fourth lesson, we had told students that we would be trying to create a tornado in the classroom on our next visit and we had brainstormed with them some materials we might need for this project: fans, spray bottles, bowls, and dry ice. Students chose fans to create wind and the spray bottles, because we had talked about humid air. They chose dry ice because it had been used recently in a school function, and
the students knew that it formed fog, which they thought could be useful in trying to “see” the tornado they would create in the classroom.

When a teacher offers this kind of inquiry experience to a class, a lot of preplanning is needed, even if there is no predetermined path. The teacher should be aware of the potential hazards in the materials that are offered, make sure that the space and class sizes are appropriate, and discuss precautions with students. When student groups plan their own inquiry, they should think about their own safety plan and have it checked with the teacher. Before students handled any materials, we talked about safety procedures and established that the dry ice was to be handled only by teachers who would be wearing goggles and protective gloves. We also marked off a tornado “zone” so students could not reach the dry ice. In addition, we made sure water was kept away from the fan plugs and that the fans had screen finger guards.

When my colleagues and I arrived with the materials, I introduced the challenge. I explained how we (the teachers) wanted to show the class a tornado, but there was not a specific formula for creating one in a classroom setting. I told them that we had taught them a lot about how tornadoes are formed, and, if they used each other as resources, they would be able to try to create a tornado. Within minutes the kids were in groups formulating predictions and designing experiments.

Then, students started their experiments. We approved each one before they began but offered students no other help in the process except for handling the dry ice for safety purposes. When necessary, we asked guiding questions (What happened when you changed the position of the fan? Why did you make that decision?), referring them to their science journals so they could try each idea in an organized way. It was amazing to watch the students’ faces as they saw each experiment begin to work in one aspect but fail in another. For example, one group had every fan pointed toward the bowl of dry ice to try to force the air up in a twister. Another group thought that they could create an upside-down twister by having the dry ice on the top of a file cabinet and trying to move the “smoke” (what the children called the frozen water vapor) as it floated to the ground. Another group used the spray bottles to try to mix dry air with humid air.

I could see lightbulbs turning on in their minds. They spoke of the learning that had occurred earlier as they wrestled with their new challenge. They referred to parts of other experiments like fan placement and what kind of water created the most “smoke.” They also took notes on what worked in their journals. They had to apply what they had learned about the atmospheric conditions from our weather forecaster lesson—air from two different directions has to combine—and what they had studied from using two-liter tornado bottle simulations—we put Monopoly houses in the bottles so the students could see in what direction the twisters were forming.

A Whirl of Learning

I wish I could say that students created a tornado, but they did not. They also did not realize that they “failed.” In our wrap-up discussion that day, students admitted that they got close enough that they could now visualize the conditions necessary to simulate a tornado. We discovered that if you turn a box fan upside down the air will “pull the ‘smoke’ upward.” To get it to spin, you need two fans pushing the air in opposite directions. The twister can reach only a few feet, but it does twist once you get the fans in the right position.

There was not a single child in that classroom who was not involved in that discussion. Students were listening to what their peers were saying, because they had something to add to elaborate on the idea even more. We also took the conversation into what went wrong and how they were able to problem solve. They used the knowledge and processes of investigation—trial and error, problem solving—that we had guided them through and, by themselves, were able to come close to a product that was presented to them as nearly impossible.

Students were so excited about the process
they may not remember that they could not replicate a tornado. What they will likely remember is that they were given the opportunity to realize that science is truly a verb as well as a noun and that they loved the experience.

Keeping the Spark
Reflecting on the success of the tornado lesson, I tried to come up with a formula or a list of guidelines for myself for creating and maintaining this kind of spark in a classroom again. What I came up with was this: An inquiry-based lesson

• is more than the lesson idea or the proper equipment. It involves trusting your students to learn when you give them the time and responsibility to think on their own. Provide students the tools to know how to problem solve, give them guidelines on working with others, provide safety reminders, and let them explore. Our job as teachers is to circulate and guide students with questions as they discover the solutions.
• is the kind of activity in which everyone in the class can be involved; it may turn out that this is where a struggling student can really shine.
• can teach about more than just concepts. It gives students a process to use when they encounter other problems in and out of the classroom.
• allowed me to see the students use information to create something.

Perhaps more than anything else, the lesson changed the classroom atmosphere from presentation to discovery and application. I was no longer just a performer—I was someone who knew what the students could do and gave them a stage on which to perform. That is something that will be very hard for anyone who witnesses it to forget.

The tornado experience really surprised me. Not only did my group do something fantastic with a group of fifth graders that really sparked their interest, but the experience also sparked an interest in science in me and helped open my eyes to new opportunities. As a result of the lesson, I decided to intern at the Science Center of Iowa to teach inquiry-based projects to elementary students. I have continued to work with Drake students and the Science Center to promote inquiry in the classroom. I am in my second year of teaching and continue to incorporate inquiry-based learning in my classroom.

Three years ago, if someone had told me I would be excited by teaching with a science-based method I would have rolled my eyes, but this experience has changed me and my approach to almost everything in my classroom.

Kaitlyn Hood is in her second year of teaching for Des Moines Public Schools. Jack A. Gerlovich is a professor of science education at Drake University in Des Moines, Iowa.

Resources

Internet
Tornado Lesson Plan
www.educ.drake.edu/gerlovich/tornadoes

Connecting to the Standards
This article relates to the following National Science Education Standards (NRC 1996):

Teaching Standards
Standard A:
Teachers of science plan an inquiry-based science program for their students.
Section 1

The Nature of Science and Science Inquiry
The Nature of Science and Science Inquiry

What Is Science?

Science is a systematic process of learning about the natural world. Scientists attempt to understand the world by making careful observations and creating theories to explain those observations. They make observations in many settings and may observe phenomena passively, make collections, or actively probe the world. In some cases, scientists may control conditions through an experimental method (see p. 6). By focusing on the natural world, science precludes the use of the supernatural or magic as acceptable evidence or explanations. There are some questions that science simply cannot address. Science cannot investigate matters of religious faith, good versus evil, or beliefs such as astrology and supernatural hauntings. Because science is a human endeavor, the possibility of bias does exist. Through the process of examining evidence, however, bias is generally corrected over time.

A theory is a model of how a specific aspect of the world works. A theory becomes widely accepted as it becomes more precise and can be used to make predictions about the natural world. The big bang theory, for example, came about as scientists tried to explain observations that were consistent with an expanding universe. Among other predictions, the big bang theory predicted the ratio of hydrogen to helium in the universe and the background temperature of the universe. As scientific observations confirmed these predictions, the theory became widely accepted and alternative explanations were rejected. Like all models, theories are not absolute truth, but are approximations of the natural world. Because they are approximations of the natural world, they are subject to change: Although a theory may fit observations well, modifications to the theory or an alternate theory may lead to a better fit. Modification of ideas rather than outright rejection is the norm for theories that have become widely accepted.

What Should Science Look Like in the Classroom?

A knowledge-centered science classroom focuses on science concepts and processes. Social constructivism, pioneered by the Russian psychologist Lev Vygotsky (1987), views knowledge construction as a result of indi-
individuals interacting in social environments. The activity by which knowledge is developed is not separable from the learning that is taking place. This means that, if the classroom does not reflect the culture of science, students will not have a full appreciation of the science content presented in that classroom. If science is presented to students only as a body of facts to memorize, students will view science as a collection of facts rather than what it is: a way of understanding the natural world.

In a knowledge-centered science classroom, students work to answer scientifically oriented questions by creating explanations based on evidence. This approach, called science inquiry, is how science is conducted. It creates a learning environment that reflects the culture of science. The National Research Council (1996) states that “inquiry into authentic questions generated from student experiences is the central strategy for teaching science.” Inquiry teaching as described by the NRC has the following essential features:

1. The learner engages in scientifically oriented questions.
2. The learner gives priority to evidence in responding to questions.
3. The learner formulates explanations from evidence.
4. The learner connects explanations to scientific knowledge.
5. The learner communicates and justifies explanations.

Variations in inquiry strategies can be described on a continuum based on the amount of teacher intervention.

- **Open (or Full) Inquiry**, involves the least authoritative intervention by the teacher. Students generate questions and design and conduct their own investigations.
- **Guided Inquiry** involves more direction from the teacher and generally involves the teacher presenting students with the question to be investigated. Students then plan and conduct their own investigations to answer the question.
- **Structured Inquiry**, teachers provide students with a series of questions and directions for investigations that students should complete. This is a more authoritative intervention: The teacher provides the problem and processes, but students are able to identify alternative outcomes.

Table 1 illustrates the variations in teacher control for each characteristic of science inquiry. Incorporating inquiry into your teaching requires that you strategically decide how much control to exercise over the inquiry process. Your decisions should support student learning and take into account your students’ readiness to participate in inquiry.

In 2002, Chinn and Malhotra examined more than 400 activities found in nine commonly used middle school textbooks to determine how well they reflected characteristics of science inquiry. They found that nearly every activity failed to incorporate elements of science inquiry. To create a classroom environment focused on science inquiry, you will need to modify most of the activities that you use. The following list suggests simple modifications that you can make:

1. Have students create their own data tables.
2. Have students create their own procedures.
3. After completing the activity, ask students to pose questions for further research.
4. Focus students on providing evidence for every conclusion that they make.
5. Create “sentence strips” out of the procedures and have students properly sequence them.
6. Move the activity to the beginning of instruction. Have students complete the
<table>
<thead>
<tr>
<th>Essential Feature</th>
<th>Variations</th>
<th>Amount of Learner Self-Direction</th>
<th>Amount of Direction from Teacher or Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learner engages in scientifically oriented questions</td>
<td>Learner poses a question</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td></td>
<td>Learner selects among questions, poses new questions</td>
<td>Learner sharpens or clarifies question provided by teacher or other source</td>
<td>Learner given data and told how to analyze</td>
</tr>
<tr>
<td></td>
<td>Learner formulates explanation after summarizing evidence</td>
<td>Learner guided in process of formulating explanations from evidence</td>
<td>Learner given possible ways to use evidence to formulate explanation</td>
</tr>
<tr>
<td></td>
<td>Learner communicates and justifies explanations</td>
<td>Learner given steps and procedures for communication</td>
<td>Learner provided broad guidelines to sharpen communication</td>
</tr>
<tr>
<td>2. Learner gives priority to evidence in responding to questions</td>
<td>Learner determines what constitutes evidence and collects it</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td></td>
<td>Learner formulates explanations from evidence</td>
<td>Learner formulates explanations from summarizing evidence</td>
<td>Learner formulates explanations from scientific knowledge</td>
</tr>
<tr>
<td></td>
<td>Learner communicates and justifies explanations</td>
<td>Learner given steps and procedures for communication</td>
<td>Learner provided broad guidelines to sharpen communication</td>
</tr>
<tr>
<td>3. Learner connects explanations to scientific knowledge</td>
<td>Learner integrates evidence into new knowledge</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td></td>
<td>Learner examines other resources and forms the links to explanations</td>
<td>Learner independently examines other resources and forms the links to explanations</td>
<td>Learner formulates explanations from scientific knowledge</td>
</tr>
<tr>
<td></td>
<td>Learner communicates and justifies explanations</td>
<td>Learner given steps and procedures for communication</td>
<td>Learner provided broad guidelines to sharpen communication</td>
</tr>
<tr>
<td>4. Learner connects explanations to scientific knowledge</td>
<td>Learner communicates and justifies explanations</td>
<td>More</td>
<td>Less</td>
</tr>
<tr>
<td></td>
<td>Learner given data and told how to analyze</td>
<td>Learner given data and asked to analyze</td>
<td>Learner given data and asked to analyze</td>
</tr>
<tr>
<td></td>
<td>Learner given possible ways to use evidence to formulate explanation</td>
<td>Learner given possible ways to use evidence to formulate explanation</td>
<td>Learner given possible ways to use evidence to formulate explanation</td>
</tr>
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<td></td>
<td>Learner given steps and procedures for communication</td>
<td>Learner given steps and procedures for communication</td>
<td>Learner provided broad guidelines to sharpen communication</td>
</tr>
</tbody>
</table>

Table 1. Description of Various Levels of the Essential Features of Classroom Inquiry

Source: Data from National Research Council. 2000.
activity before they are introduced to the content.
7. Provide time for students to “mess about” with the materials before they begin their investigation.
8. Provide students with options of what or how they investigate.
9. Hold a “scientist meeting” prior to the activity to discuss possible questions for investigation or investigation procedures.
10. Hold a “scientist meeting” after the activity to discuss outcomes, conclusions and supporting evidence.

What Skills Do Students Need?
Students need to develop a variety of skills to fully participate in inquiry.

- Students should have frequent opportunities to observe objects and events. Good observations should include information gathered from multiple senses and may involve scientific instruments.
- Students should make educated guesses, or inferences, based on observations.
- Students should be able to measure using standard (including metric) and nonstandard tools.
- Students should be able to classify objects or events into categories based on criteria.
- Students should be able to use words, symbols and graphical representations of data to communicate ideas.
- Students should be able to interpret data by organizing data and identifying patterns.

Table 2 describes age-appropriate performances for each of these skills.

What Is the Experimental Method?
One process by which scientists create new knowledge is called the experimental method. It consists of a series of well-defined steps that test one aspect of a phenomenon while holding the others constant. Many K–12 textbooks call the experimental method the scientific method. This is not accurate, however, because the experimental method is only one of the processes that scientists use.

The experimental method involves the following steps:

1. Identifying a problem that can be investigated and determining the independent and dependent variables. Independent variables are those that can be easily changed or controlled. Dependent variables are those that are affected by the independent variables.
2. Stating a hypothesis. Experimenters should pick one independent variable and one dependent variable to test. They should then create a statement of how the independent variable will affect the dependent variable.
3. Testing a hypothesis. Experimenters design a “fair test” of their hypothesis. In a fair test, the independent variable is changed, the dependent variable is measured and the other variables are held constant.
4. Analyzing results. Students try to make sense of their data.
5. Communicating conclusions. Students compare their results to their initial hypothesis and communicate their results.

Table 3 describes age-appropriate experimentation.
### Table 2.
Age-appropriate performances for science process skills

<table>
<thead>
<tr>
<th>Skill</th>
<th>Grades K–1</th>
<th>Grades 2–3</th>
<th>Grades 4–5</th>
<th>Grades 6–8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observing</td>
<td>Students should be able to make basic observations using all five senses. Students should be able to make observations regarding color, size, and shape. Students should be able to use some basic scientific tools (e.g., hand lenses) to assist in making observations.</td>
<td>Students, with help, should be able to decide what observations are needed in order to provide useful data. Although most observations will be qualitative, students should begin making some quantitative observations. Students should be able to explain results or conclusions using observations.</td>
<td>By this age, observations using multiple senses should be natural for students. Students should be comfortable determining what observations are useful and identifying proper scientific tools to assist in making observations. Students should be able to make qualitative and quantitative observations. Student conclusions should be supported by their observations.</td>
<td>Students should be able to explain that scientific inquiry is not possible without accurate observations. Students should be able to describe how technological advances have helped scientists make more accurate and new observations that have lead to new scientific knowledge.</td>
</tr>
<tr>
<td>Inferring</td>
<td>Students should work with objects and activities that are relevant to them. They can make simple observations and make inferences as to why something happened, but with little background knowledge, based on their experiences.</td>
<td>Students have had more experiences, but not a lot yet. They are able to better analyze data to make simple inferences and predictions about their experiments.</td>
<td>Students are growing developmentally and at this stage can use scientific tools, equipment, logical reasoning, resources, and dichotomous keys as ways to help develop their inferences.</td>
<td>At this level, students are able to use the data they collected to support and explain their scientific inferences. They are also able to discuss ideas and results with peers, teachers, and other adults.</td>
</tr>
<tr>
<td>Classifying</td>
<td>Students should be able to sort objects into groups or categories based on common properties (color, size, shape, use). Students should be able to group objects by a single characteristic.</td>
<td>Students should be able to form groups that are subordinate to a larger group. Students should recognize that the same object may have more than one attribute or characteristic that can be used in classification.</td>
<td>Students should be able to form groups that are mutually exclusive. Students should also be able to abstract the general attributes of objects in a collection.</td>
<td>Students should be able to form hierarchical classification systems.</td>
</tr>
</tbody>
</table>

**IMPORTANT:** Students should follow teacher directions for safe observing. Students should not use smell, taste, or touch when observing hazardous materials. The use of hazardous materials should be avoided in elementary grades.

---

**NOTE:** Contributed by University of Wisconsin–La Crosse science methods students during the fall 2007 semester.

(Cont on p. 8)
### Communicating
Students should be able to share personal information (show and share), create basic graphs and read simple graphs and charts. Students should be able to describe objects, tell stories, and participate in playacting.

### Measuring
Students should be able to measure length and volume of simple objects using standard and non-standard units. Students should be able to read a thermometer and clock and be able to compare temperatures. At this age, student measurements should be to the nearest whole number.

### Interpreting Data
Students should be able to report the results of science investigations to different audiences (friends, teachers, family) by using simple graphs, tables and illustrations. Students should be able to collect simple data from investigations.

### Communicating
Students should be able to create and read graphs, charts and diagrams. Students should explore number sentences and participate in journaling and teacher conferencing.

### Measuring
Students should be able to measure intervals of time and compare weights. Students should become familiar with Fahrenheit and Celsius temperature scales.

### Interpreting Data
Students should be able to use evidence to explain and justify results and conclusions. Students should recognize that there are multiple sources of information available to answer questions.

### Communicating
Students should be able to complete group projects, communicate ideas through poster making, and use diagrams to explain information. Students should also be able to create more complicated graphs and charts.

### Measuring
Students should be able to estimate the distance between points, weigh and compare objects, and identify the freezing and boiling points of water. Measurements should be made using fractions.

### Interpreting Data
Students should be able to identify sources of data and be able to determine and explain which data are needed to answer a scientific question. Students should use data to support scientific conclusions. Students should routinely incorporate and discuss graphical representations of data.

### Communicating
Students should be able to deliver individual and group presentations and use mathematical equations and explanations to describe results.

### Measuring
Students should be able to determine volume by displacement and understand the difference between weight and mass. Students should be able to measure using the metric system.

### Interpreting Data
Students should be able to use collected data to support and explain scientific inferences. Students should be able to critique experimental designs and procedures. Students should be able to use qualitative and quantitative data from multiple sources to develop and defend scientific conclusions.
### Table 3.
Age-appropriate experimentation

<table>
<thead>
<tr>
<th>Grades K–1</th>
<th>Grades 2–3</th>
<th>Grades 4–5</th>
<th>Grades 6–8</th>
</tr>
</thead>
</table>
| Students participate in simple investigations.  
- asking questions  
- making observations  
- identifying what variable may be causing another to change.  
- selecting equipment for and conducting simple investigations  
- collecting some data  
- reporting the results of the investigations to others by using simple graphs, tables, and illustrations | Students are able to conduct an investigation, interpret the results and modify questions accordingly:  
- planning a simple investigation  
- deciding what observations are needed to explain the results  
- acquiring the sense that there might be more than one variable that is causing a particular happening, and decide how they are going to investigate that.  
- predicting the results of the investigation  
- conducting simple investigations  
- using evidence collected to explain results  
- selecting relevant equipment to use during the investigations  
- identifying data relevant to their questions and investigations  
- interpreting data  
- developing additional questions that support new investigations on the original topic | Students are able to create their own experiments and all characteristics are appropriate for this age:  
- identifying questions that can be answered with available equipment  
- determining which equipment is most logical to answer each question  
- determining if the questions are testable  
- identifying sources of data  
- determining which data is needed to answer the question  
- explaining the results of an investigation to others using multiple forms of communication  
- verifying the results through other experimentation | Students are moving from the concrete stage to the abstract stage and are more able to be creative in planning experiments and analyzing results:  
- discussing the results and implications of an investigation  
- deciding if the results are logical and accurate  
- raising further questions after the experiment is done  
- collecting data and defending the validity of the experiment  
- developing alternative hypotheses for the question  
- designing and conducting investigations |

**NOTE:** Contributed by Rachel Knutowski.
The Articles
This section contains seven articles that illustrate teaching that builds a learning environment conducive to student understanding of the nature of science and science inquiry.

Article: A Literature-Circles Approach to Understanding Science as a Human Endeavor
Key Ideas: This article describes an approach to help students gain an understanding of the nature of science by reading and discussing nonfiction.

Article: Light Students’ Interest in the Nature of Science
Key Ideas: After students learn about electric circuits, they are challenged to explain how a “light up” shoe works. Students make observations and develop an explanatory theory for how the shoe works. This article describes connections between the activity and how scientific knowledge is created.

Article: Did You Really Prove It?
Key Ideas: This article describes four strategies for reinforcing the nature of science throughout the school year.

Article: An Inquiry Primer
Key Ideas: This article provides an overview of science inquiry by providing answers to questions commonly asked by teachers.

Article: Inquiry Made Easy
Key Ideas: This article describes a step-by-step process for introducing science inquiry into your teaching.

Article: Blow-by-Blow Inquiry
Key Ideas: This article describes the “Experimental Method” in progress. The authors also provide examples of how to scaffold students into inquiry.

Article: Why Do We Classify Things in Science?
Key Ideas: In this article, the author explains how scientists use classification to help them make sense of new things. The author explains why this skill is important in the classroom.

Action Steps
2. Read Chapter 1 of AAA’s Science for All Americans at www.project2061.org/publications/sfaa/online/chap1.htm.
3. Watch NOVA’s Judgment Day: Intelligent Design on Trial and describe how the show illustrates examples of the nature of science and examples of nonscientific thought at www.pbs.org/wgbh/nova/id.
4. Find a “cookbook” activity from the internet, a textbook, or an activity guide. Modify the activity so that it includes all of the characteristics of science inquiry. Try making modifications to create a guided-inquiry activity and an open-inquiry activity.

Reflection Questions
1. How is the popular use of the word theory different from the scientific use of the word?
2. What might a rubric for student understanding of the nature of science look like? What are the most basic ideas that students should master? What are the more complicated ideas?
3. Compare and contrast national or state standards for science inquiry for grades K–4 and 5–8. (Go to National Science Education Standards, Chapter 6 at www.nap.edu/readingroom/books/nses/)
4. Describe activities that you could use to introduce and reinforce the skills necessary to engage in science inquiry.
5. How do the selected articles exemplify the nature of science and the characteristics of science inquiry? If you were going to use these in the classroom, what changes would you make?

6. Under what circumstances would a high amount of teacher control in science inquiry be beneficial? A low amount of teacher control?

References
A Literature-Circles Approach to Understanding Science as a Human Endeavor

By William Straits

The National Science Education Standards suggest that middle school science teachers use “historical examples … to help students see the scientific enterprise as more philosophical, social, and human” (NRC 1996). Fortunately for today’s science teachers, science-related, historical nonfiction has become a popular literary genre. Teachers can select books on a wide range of topics to help learners of all ages explore the history and nature of science. (See Figure 1 for a list of titles appropriate for young adolescents.) The reading of these books alone, however, does not necessarily lead students to make personal connections to science or to understand science as a human endeavor interdependent with culture, society, and history. Teachers must structure students’ reading to ensure that they consider specific aspects of science while reading and discussing books. One way for teachers to focus their students’ attention on components of the nature of science is through the use of literature circles.

Literature Circles
Literature circles were initially developed for young adolescents’ classroom reading (Daniels 1994) and have since grown to be a very popular choice for middle school language-arts teachers. Literature circles are “small, temporary discus-
Figure 1.
List of texts appropriate for middle school students’ explorations of the history and nature of science. These books are suitable for long-term reading assignments.

<table>
<thead>
<tr>
<th>Biographies of scientists</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Galileo: Astronomer and Physicist</td>
<td>R.S. Doak</td>
</tr>
<tr>
<td>The Wright Brothers: How They Invented the Airplane</td>
<td>R. Freedman</td>
</tr>
<tr>
<td>Curious Bones: Mary Anning and the Birth of Paleontology</td>
<td>T.W. Goodhue</td>
</tr>
<tr>
<td>Issac Newton</td>
<td>K. Krull</td>
</tr>
<tr>
<td>Always Inventing: A Photobiography of Alexander Graham Bell</td>
<td>T.L. Matthews</td>
</tr>
<tr>
<td>Something Out of Nothing: Marie Curie and Radium</td>
<td>C.K. McClafferty</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Historical accounts of science</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Phineas Gage: A Gruesome but True Story About Brain Science</td>
<td>J. Fleischman</td>
</tr>
<tr>
<td>The Planet Hunters: The Search for Other Worlds</td>
<td>D.B. Fradin</td>
</tr>
<tr>
<td>Fossil Feud: The Rivalry of the First American Dinosaur</td>
<td>T. Holmes</td>
</tr>
<tr>
<td>An American Plague: The True and Terrifying Story of the Yellow Fever Epidemic of 1793</td>
<td>J. Murphy</td>
</tr>
<tr>
<td>Scientific Explorers: Travels in Search of Knowledge</td>
<td>R. Stefoff</td>
</tr>
</tbody>
</table>

sion groups” in which students are provided prompts or roles (Daniels 1994). The purpose of literature-circle roles is to guide students to develop understanding of particular concepts as they explore the text and meaningfully participate in small-group discussion. As students are reading, they perform specific roles and take notes that are used to support participation in small-group discussion. Several basic roles appropriate for the reading of most books have been offered by Daniels (1994) (see Figure 2). In addition to these all-purpose roles, others have been designed specifically with the goals of focusing students’ attention to issues of the nature of science and promoting students’ connection with science as they read historical nonfiction (Straits 2005; Straits 2007):

- Everyday life connector—Search the reading for events, ideas, characters, objects, and so on that remind you of everyday life. Pay particular attention to science concepts.
- Science skeptic—Analyze how science is done in the book. How does it compare to our inquiry investigations? Consider specific aspects of experimental design. For example, are scientists in the book controlling variables, repeating their tests, avoiding bias, and using a large enough sample size?
- Power investigator—Sometimes people with political, social, and/or economic power influence science. For example, they might determine who does science and who does not, or which ideas are investigated and which are not. Find out which group(s) have power and list a few ideas about how they are using their power to help or get in the way of scientists.
• Science translator—While reading, take note of science vocabulary and concepts in the book. Use the internet, textbook, and other sources to find out more information about these ideas.
• Historian—Scientific developments of the past are described in the book. Find out other things that happened at the same time (e.g., 1368–1644, Ming Dynasty; 1819, birth of Walt Whitman; 1908, Chicago Cubs win World Series)
• Science biographer—As you encounter different people doing science in the reading, use sources such as the textbook and the internet to locate interesting biographical information about each person, especially those connected to science.
• Nature-of-science investigator—Factors that accurately describe science include scientific knowledge is based on evidence; scientists can never know for certain that a conclusion is correct; scientific knowledge changes over time; there are multiple ways to solve problems in science; scientists are often very creative in their attempts to solve problems; and scientists are people, influenced by their own personal beliefs and by society. While reading, look for examples of these factors in the book.
• Science and culture connector—Science is greatly influenced by culture (the beliefs and values of particular societies at particular times in history). Consider ways science was influenced by culture in the past and ways that science is influenced by our culture today.

Group meetings are important times of learning as they provide a forum for active reflection that promotes the development and sharing of meaningful, personal connections to learning. During discussion in their small groups, students can use information gathered via their roles to help clarify meaning, draw parallels to other situations, articulate related personal experience, offer additional information, critique and analyze the text, and connect the text to the nature of science and investigative skills learned in class. Although discussions are prompted and guided by literature-circle roles, conversations are far from limited to simply reporting information; roles should enrich conversations, not delineate them. It should be made explicit to students that “group meetings aim to be open, natural
conversations about books, so personal connections, digressions, and open-ended questions are welcome” (Daniels 1994). In fact, it is these personal connections that are of particular value when discussing the interaction between science and social influences such as economics, history, culture, politics, and so on. For example, while discussing a book about inventions or discoveries of the past, students may talk about current events, their own family and personal experiences, as well as any number of topics ranging from professional athletes to today’s environmental policies and concerns.

At the conclusion of each discussion, group members rotate roles and decide on a new section of text to be read. When the entire text has been completed, often after several group meetings along the way, group members create a presentation that represents their understanding of the topics/texts explored. These final presentations may take on any number of creative forms, such as impersonations of characters, an interview with the impersonated author(s), a news broadcast reporting events from the text, or a eulogy for a character (the preceding suggestions as well as many others are explained in Daniels 1994). Final presentations are valuable as they require students to organize information in unique ways, thereby demanding higher-level learning. The presentations serve as an opportunity for assessment and arouse the interest of other students in the topics/texts presented. If time allows, students can then choose new topics/texts, form new groups, and begin another round of literature circles.

Why Literature Circles Work
Readers may approach a book from an information-based or emotion-based stance, depending on their individual purposes for reading. The information-based, or efferent, stance accentuates the meaning readers take from the book, whereas the emotion-based, or aesthetic, stance prioritizes the previous experiences that readers bring to the text (Rosenblatt 1978). As they are reading a book, readers may be oriented to any point along the continuum between efferent and aesthetic, based on textual clues and an individual’s expectations and reasons for reading. For example, most fictional books orient readers toward the aesthetic. There is often, however, a great deal of information to be taken from these texts.

Consider Jack London’s To Build a Fire, in which London visits a familiar theme, the folly of man’s presumed superiority over nature. In this short story, a man and a dog take an ill-fated hike in the subfreezing temperatures of the Yukon Territory and the man’s fear, panic, and ultimate acceptance of death are detailed as he freezes to death, unable to build a fire. Readers may bring with them fear of cold, hunger, and death, fears that surface in them as they read. However, they can also take from this story information about seasonality and the tilt of the Earth, the biotic and abiotic features of the taiga, and human physiology and thermoregulation. Similarly, students come prepositioned toward the efferent while reading most assigned science texts, including historical nonfiction. To identify with science and to see it truly as a human struggle, endeavor, passion, and need, students must be taken explicitly from their efferent stances and guided to view science reading from an aesthetic stance. Literature-circle roles are invaluable as they can guide learners toward both efferent and aesthetic interactions with text.

Final Considerations
Literature circles are an extremely flexible instructional strategy; there is no one right way to use them. But as you plan your instruction you may want to consider these lessons learned.

- Text selection—Success with literature circles depends on the text selected as well as the reading interests and abilities of students. In selecting books to use,
it is beneficial if the topic(s) covered in the text parallel concepts taught in class. For example, classroom instruction about atomic theory, isotopes, and radioactive decay should be provided in concert with literature circles reading books that describe Marie Curie or the Manhattan Project. Your students are another important consideration in text selection. Ask colleagues or review student files to get a sense of individuals’ reading abilities. Encourage students to select texts at their reading level. Finally, don’t judge a book by its cover; be sure to read the books yourself before assigning them.

• Group size—Not all literature-circle roles need to be completed by each student or in preparation for each group meeting; group size is not dictated by the number of roles. Rather, group size should maximize the participation and learning of group members. Groups of three to five are generally preferred as they are large enough to allow for varying viewpoints and rich conversation and small enough to allow opportunities for members to contribute.

• Time—A basic premise of the circles is that the most meaningful learning comes not from the reading of text, but from the discussion of text. Optimally, students would meet in their discussion groups two or three times per week. However, more important than the number of meetings is the length of the meetings. As with most science instruction, longer intervals of time are ideal. Allot a minimum of 25 to 30 minutes per group meeting. If your schedule allows 60 minutes per week for discussion groups to meet, consider two longer meetings rather than three short ones. Whatever schedule you decide, stick to it! A recipe for disaster is to hold literature-circle meetings “if time permits.” Depending on the frequency of meetings and the length and difficulty of the texts, a single literature-circle cycle may last a few to several weeks. Whatever the duration, throughout the reading assignment remember that reading their texts and performing literature-circle roles represent a significant time demand for students—adjust other homework assignments appropriately.

• Assessment—Monitoring student discussion and roles can provide opportunities to give students feedback about their preparation for and participation during discussions. In addition to serving as formative assessment, monitoring student discussion will allow teachers to gather ideas for more formal assessments. Guided by roles, students will often ask extremely important discussion questions, compelling group members to explore personally meaningful connections to the text and the science presented within it. These very questions may be used later as individual summative assessments. Finally, group presentations provide opportunities for students to engage in higher-level learning as they synthesize a representation of their learning from the text and discussions and provide opportunities for you to assess each group’s ultimate learning outcomes.

• Teacher’s role—During discussions the teacher’s role is one of facilitator. Productive and meaningful group discussion does not just happen; students will require support and prompting as they learn to discuss respectfully and productively. Taking time as a class to brainstorm the elements of productive discussions can be a valuable exercise. Also, as you read the texts in preparation for literature circles, it’s helpful if you perform some of the roles yourself. These will provide you with questions, discussion topics, insights, and connections of your own to offer to groups that may need some prompting.
during their discussions. Finally, when all other groups are running smoothly, it is a great idea to join a literature circle as a group member. This participation has two key benefits. It will allow you to demonstrate for your students techniques for productive, respectful, and inclusive discussion and, most important, it will allow your students to see an adult’s genuine enthusiasm for reading about the history of science.

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