Exemplary Science in Grades 5–8

Standards-Based Success Stories

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NSTApress
NATIONAL SCIENCE TEACHERS ASSOCIATION
Arlington, Virginia

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08 07 06 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Exemplary science in grades 5-8 : standards-based success stories / [edited] by Robert Yager.
p. cm.
Includes bibliographical references and index.
ISBN 0-87355-262-8
1. Science--Study and teaching (Middle school) I. Yager, Robert Eugene, 1930-
Q181.E94 2006
507'.1'273--dc22
2005016739

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How This Book Came About

Nine years have elapsed since the 1996 publication of the National Science Education Standards (NSES) (NRC 1996). The critical issues in science education now are these: How far have we progressed in putting the vision of the NSES into practice? What remains to be done? What new visions are worthy of new trials?

The four monographs in the NSTA Exemplary Science Monograph series seek to answer these questions. The monographs are *Exemplary Science: Best Practices in Professional Development*; *Exemplary Science in Grades 9–12*; *Exemplary Science in Grades 5–8* (the book you are reading); and *Exemplary Science in Grades K–4*.

The series was conceived in 2001 by an advisory board of science educators, many of whom had participated in the development of the National Science Education Standards. The advisory board members (who are all active and involved NSTA members; see p. xiii for their names) decided to seek exemplars of the NSES' *More Emphasis* conditions as a way to evaluate progress toward the visions of the NSES. The *More Emphasis* conditions provide summaries of the NSES recommendations in science teaching, professional development, assessment, science content, and science education programs and systems. (See Appendix 1 for the six *Less Emphasis*/*More Emphasis* lists.) The board sent information about the projected series to the NSTA leadership team and to all the NSTA affiliates, chapters, and associated groups. A call for papers on exemplary programs also appeared in all NSTA publications. In addition, more than a thousand letters inviting nominations were sent to leaders identified in the *2001–2002 NSTA Handbook*, and personal letters were sent to leaders of all science education organizations.

After preliminary responses were received, the advisory board identified teachers and programs that it felt should be encouraged to prepare formal drafts for further review and evaluation. The goal was to identify 15 of the best situations in each of the four areas—professional development and grades 9–12, 5–8, and K–4—where facets of the teaching, professional development, assessment, and content standards were being met in an exemplary manner.

The most important aspect of the selection process was the evidence the authors of each article could provide regarding the effect of their programs on student learning. This aspect proved the most elusive. Most of us "know" when something is going well, but we are not well equipped to provide real evidence for this "knowing." Many exciting program descriptions were not among the final titles—simply because little or no evidence other than personal testimony was available in the materials forwarded. The 15 middle school models that make up this monograph were chosen by the advisory board as the best examples of programs that fulfill the *More Emphasis* conditions; each has had a clear, positive impact on student science learning.

The History of the National Science Education Standards

Before discussing the contents of this book at greater length, I would like to offer a brief history of how the National Science Education Standards came to be.

Most educators credit the National Council of Teachers of Mathematics (NCTM) with initiating the many efforts to produce national standards for programs in U.S. schools. In 1986 (10 years before the publication of the National Science Education Standards), the board of directors of NCTM established a Commission on Standards for School Mathematics with the aim of improving the quality of school mathematics. An initial draft of these standards was developed during the summer of 1987, revised during the summer of 1988 after much discussion among NCTM members, and finally published as the *Curriculum and Evaluation Standards for School Mathematics* in 1989.

The NCTM standards did much for mathematics education by providing a consensus for what mathematics should be. The National Science Foundation (NSF) and other funding groups had not been involved in developing the math standards, but these groups quickly funded research and training to move schools and teachers in the direction of those standards. Having such a "national" statement regarding needed reforms resulted in funding from private and government foundations to produce school standards in other disciplines, including science.

NSF encouraged the science education community to develop standards modeled after the NCTM document (1989). Interestingly, both the American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA) expressed interest in preparing science standards. Both organizations indicated that they each had made a significant start on such national standards—AAAS with its Project 2061 and NSTA with its Scope, Sequence, and

Coordination project. Both of these national projects had support from NSF, private foundations, and industries. The compromise on this "competition" between AAAS and NSTA leaders led to the recommendation that the National Research Council (NRC) of the National Academy of Sciences be funded to develop the National Science Education Standards. With NSF funding provided in 1992, both NSTA and AAAS helped to select the science leaders who would prepare the NSES. Several early drafts were circulated among hundreds of people with invitations to comment, suggest, debate, and assist with a consensus document. A full-time director of consensus provided leadership and assistance as final drafts were assembled. Eventually, it took $7 million and four years of debate to produce the 262-page NSES publication in 1996.

There was never any intention that the Standards would indicate minimum competencies that would be required of all. Instead, the focus was on visions of how teaching, assessment, and content should be changed. Early on, programs and systems were added as follow-ups to teaching, assessment, and content.

NSES and the Middle School Science Classroom

The philosophy of the middle school in the United States matches the *More Emphasis* conditions of teaching. In many respects, the middle school teachers have found it easy to be more "student centered," to be more collegial with other teachers, and to work on common projects across the curriculum. The mix of teachers with secondary school endorsements and the nearly one-half with elementary school licenses and teaching focus provides for more cross-pollination in terms of discipline/curriculum focus or focus upon current, local, and relevant problems.

On one hand, it would be good if school systems could uniformly designate the five though eight grade levels as middle school grades. However, with the more typical K–5 elementary school, 6–8 (and sometimes 9) junior high, and (either 10–12 or 9–12) high school, the middle schools have the advantage of being less rigidly defined, with fewer problems related to immediate means for fulfilling the four goals for science in the NSES. These goals are basic to middle schools; they focus on the production of students who

1. experience the richness and excitement of knowing about and understanding the natural world;
2. use appropriate scientific processes and principles in making personal decisions;
3. engage intelligently in public discourse and debate about matters of scientific and technological concern; and
4. increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.

(NRC 1996, p. 13)

The 14 *More Emphasis* conditions for continuing staff development more closely resemble what is done in middle schools—where there is less concern for an inadequate preparation in science found in teachers in elementary schools—and less emphasis on life, physical, and Earth science with few opportunities to build ideas and approaches across the high school grades.

Assessment, too, is more likely in the middle school to focus on the ways assessment practices should change as advocated in the NSES. The Standards call for more emphasis on:

1. Assessing what is most highly valued
2. Assessing rich, well-structured knowledge
3. Assessing scientific understanding and reasoning
4. Assessing to learn what students do understand
5. Assessing achievement and opportunity to learn
6. Students engaged in ongoing assessment of their work and that of others
7. Teachers involved in the development of external assessments

Reforms in the middle school provide many good reasons for optimism. First of all there is a focus on all the basic disciplines with specialists—unlike the situation in elementary schools where a single teacher is in charge of nearly the total curriculum—sometimes excepting music, art, and physical education. Middle schools basically include teachers with secondary school credentials and elementary school credentials— many times with equal numbers of each. Secondary teachers are often subject matter-bound, where elementary teachers are more focused on students, their unique problems and their struggle to learn. Getting professional teams with both interests and expertise is a worthwhile combination in terms of both a focus upon science as well as student learning.

Middle schools are also excellent places for reform since, unlike high schools, there is less singular focus on college preparation. Administrators and parents are often more willing to deal with student learning and the problems of early adolescents as opposed to a major focus on academic preparation for high school and later college.

Middle school teachers typically are organized with grade level groups and discuss and plan for the total curriculum. It is not uncommon for science teachers to work only tangentially with other science teachers and instead focus on the whole program for students in one grade level. With such a focus it is easy to organize projects around issues and problems where the concepts and skills from all areas of the curriculum come into play.

Middle schools have become more common and more philosophically attuned to standards, problem-based learning, and all four goals of the National Science Education Standards. Most prefer the name “middle school” opposed to the typical designation some decades ago as “junior high schools.” Such a term usually meant trying to keep the same discipline format as the high school—but with concern for the appropriateness of the content for 12–14-year-old students. Many more had secondary school licensure and often organized science around the same high school disciplines: life science, physical science, and Earth science.

An interesting development has occurred since the publication of the NSES with respect to the middle school designation, specifically in terms of defining “middle school” as grades 5 through 8. Although few schools have moved formally to include all four grade levels in a single building unit, many are considering the advantages. The mix of teacher preparation and interests is ideal. It is easier to focus on the goals, on assessment strategies to determine how well goals have been met, on how professional development should become part of the plan for the entire professional life of a teacher, and on local community-based problems that are both personally relevant to students' lives and current in terms of news reports and community concerns. It is easier to involve local experts, parents, administrators, and business and industrial leaders.

Conclusion

The 15 middle school exemplars all show great progress for implementing the Standards and the stated goals for science in grades 5–8. Each author team was asked to reflect on the *More Emphasis* conditions that were recommended for teaching, assessment, and content (and to some degree those concerned with the continuing education of teachers). To what extent these conditions were met by the exemplars is discussed in the final chapter.

This monograph indicates where we are with respect to meeting the visions for reforms in science for middle schools. It is important to know how our efforts during the four-year development of the NSES have impacted science classrooms. We feel that an exhaustive search has occurred during the past three years, and are impressed with what the search has revealed. We hope others reading about these exciting programs will find new ideas to try and that they will want to share more stories of their successes, especially in terms of similar experiences with their own students. We trust that this volume is an accurate record of what can be done to meet the Standards while also pinpointing some continuing challenges and needs. The exemplary programs described in this monograph give inspiration while also providing evidence that the new directions are feasible and worth the energy and effort needed for others to implement changes.

We also hope that the exemplars included will bring new meaning and life to the *More Emphasis* conditions. In many respects, the *Less Emphasis* conditions are not bad, but they do not usually result in as much learning or in ways the four goals for science teaching can be exemplified.

Hopefully the 15 examples in this monograph will serve as generators for new questions and new ideas for developing even more impressive programs so that the decade following the publication of the NSES results in even more exciting advances by 2006.

References

National Council for Teachers of Mathematics.1989. *Curriculum and evaluation standards for school mathematics.* Reston, VA: Author.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

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About the Editor

Robert E. Yager—an active contributor to the development of the National Science Education Standards—has devoted his life to teaching, writing, and advocating on behalf of science education worldwide. Having started his career as a high school science teacher, he has been a professor of science education at the University of Iowa since 1956. He has also served as president of seven national organizations, including NSTA, and been involved in teacher education in Japan, Korea, Taiwan, and Europe. Among his many publications are several NSTA books, including *Focus on Excellence* and *What Research Says to the Science Teacher.* Yager earned a bachelor's degree in biology from the University of Northern Iowa and master's and doctoral degrees in plant physiology from the University of Iowa.

Teach Them to Fish

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Setting

The reader may question how the "Teach them to fish" proverb relates to science education. Yet, a shift in emphasis from presenting knowledge through lecture and demonstration to encouraging active learning, in which students learn with understanding, exemplifies this proverb in the classroom. Lifelong learning is what we, as teachers, seek to develop in our students.

I teach sixth- and seventh-grade science in the West Branch Middle School. West Branch is a community of 2,188 people in eastern Iowa. Agriculture, manufacturing, and service industries provide the major employment opportunities in this community. The school district has 825 students, with 385 in elementary school, 195 in middle school, and 245 in high school. There is a separate building for each of these levels. In middle school, there is an average of 22–23 students per class. The schools are an important part of the community, with parents and other community members attending school events. This community is also home to the Herbert Hoover Presidential Library.

National Science Education Standards

Four goals for school science underlie the National Science Education Standards (NSES). These goals and the *More Emphasis* conditions I have addressed in my program are as follows:

1. Goal: Students experience the richness and excitement of knowing about and under-

standing the natural world.
More Emphasis conditions included in program:

Teaching Standards
- Understanding and responding to individual student's interests, strengths, experiences, and needs;
- selecting and adapting curriculum; and
- continually assessing student understanding.

Assessment Standard
- Assessing to learn what students do understand.

Content and Inquiry Standards
- Integrating all aspects of science content; and
- studying a few fundamental science concepts.

2. Goal: Students use appropriate scientific processes and principles in making personal decisions.
   More Emphasis conditions included in program:

   Teaching Standards
   - Guiding students in active and extended scientific inquiry.

   Assessment Standard
   - Assessing scientific understanding and reasoning.

   Content and Inquiry Standards
   - Understanding scientific concepts and developing abilities of inquiry;
   - implementing inquiry as instructional strategies, abilities, and ideas to be learned;
   - performing activities that investigate and analyze science questions; and
   - using evidence and strategies for developing or revising an explanation.

3. Goal: Students engage intelligently in public discourse and debate about matters of scientific and technological concern.
   More Emphasis conditions included in program:

   Teaching Standards
   - Supporting a classroom community with cooperation, shared responsibility, and respect; and
   - providing opportunities for scientific discussion and debate among students.

   Assessment Standard
   - Students engaged in ongoing assessment of their work and that of others.

Content and Inquiry Standards
- Communicating science explanations;
- applying the results of experiments to scientific arguments and explanations; and
- public communication of student ideas and work to classmates.

4. Goal: Students increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers.
More Emphasis conditions included in program:

Teaching Standard
- Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes.

Assessment Standard
- Assessing achievement and opportunity to learn.

Content and Inquiry Standards
- Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science;
- investigations over extended periods of time; and
- doing more investigations in order to develop understanding, ability, values of inquiry and knowledge of science content.

Teacher, Students, and Classroom

I have been a teacher at the sixth- through eighth-grade level for 28 years. Currently I teach sixth-grade general science and seventh-grade Earth science. I maintain ongoing professional development through graduate courses, structured inservice programs, professional associations like NSTA, both regional and national conventions and workshops, networking, professional journals such as *Science Scope*, summer institutes that are one to five weeks in length, and the development of cross-curricula activities with other colleagues in my school. Of the student body, 2.5% are minority students, and 5.2% participate in the reduced lunch fee program. My science classroom is a combined classroom/laboratory. The classroom tables are organized in the middle of the room, with laboratory tables to one side and storage along two sides. Equipment for extended projects also can be found along two sides of the room. Science classes meet every day for 45 minutes.

A Typical Day

I use a *guided inquiry* teaching approach in my classroom. This provides the students with a problem or question to investigate, a list of materials to be used, science definitions associated with the investigation, and a data table to record the information (Figure 1). I have developed these activities after scrutinizing a number of activities in books and journals. My students do hands-on inquiry activities in 85% of our science class periods. A typical class is organized in the following manner:

1. I provide 5 to 10 minutes of overview on the concept by me to lay the groundwork for the day.
2. I present the students with a question.
3. Students write answers to “I think” questions related to the question I have given them (assessing preconceptions and building upon past experience).
4. About 60–70% of the time I ask the students to share their “I think” responses, giving students an opportunity to learn what someone else thinks.
5. In paired groups, students work collaboratively to design an investigation in order to answer the question in the activity.
6. The paired groups of students carry out the investigation as I circulate through the room, observing the student activity, answering questions with questions of my own, rather than answers (as the students conduct the investigation, I can hear the questions they ask each other… “Did you notice what happened when I did…?”).
7. Students collect data, recording information in their portfolios.
8. Students develop answers to the question; if something doesn’t quite turn out the way they expected, they reconstruct their thinking and continue to explore.
9. Students write conclusions and reflect back to their answers to the “I think” question(s).
10. Students share their findings with the class; data from each group may be recorded on a white board; students see how their answers compare to their classmates.
11. I provide final closure: I may ask, “Why were the data observed and collected different between groups of students?” “Did the class do the same investigation?” “What was different or what was done differently in the investigation that caused the differences in the answers reported by the various groups?” “What did we learn…(about the question of the day)?”

With each investigation the students (a) design ways to gather information about what is known, (b) identify variables, (c) gather information and organize observations, (d) interpret their data, (e) use the evidence to develop explanations, and (f) often consider alternate explanations. A 45-minute class period is not very long, so I have developed activities that can be completed in that time, or have a natural break where we continue with the activity the next day.

More Emphasis on Teaching Standards

Selecting and Adapting Curriculum

I have developed curriculum maps for both sixth- and seventh-grade classes that organize my thinking about the units and concepts to be taught (Figure 2). The curriculum maps identify essential questions for each concept, content, and skill the students need to demonstrate (and are consistent across all units), as well as assessments, activities, and resources. The sixth-grade general science units include (a) lenses/mirrors, (b) electricity and magnets, (c) simple machines, (d) simple

Figure 1. Excerpt From an Activity on Anemometers

Investigating anemometers: Devices such as anemometers, Beaufort scales, and wind vanes are used to make short-term weather forecasts. Admiral Sir Francis Beaufort created the Beaufort scale in 1806 to indicate the strength of the wind. The British admiralty accepted the scale for the open sea in 1838 and it was adopted in 1874 by the International Meteorological Committee for international use in weather telegraphy.

I think

A. Why was the Beaufort scale developed?

B. Why is the Beaufort scale of little use in this century?

C. Winds from the south bring what type of weather conditions?

D. Winds from the north bring what type of weather conditions?

Words to know: anemometer, Beaufort scale, wind vane

Materials: anemometer, Beaufort scale, and wind vane

machines and planetary exploration, (e) planets and constellations, (f) alternative energy/solar cars, (g) life cycles, (h) timber stand improvement, and (i) chemistry.

The seventh-grade Earth science units include (a) nature of science, (b) meteorology, (c) properties of air, (d) rocks and minerals, (e) the universe, (f) groundwater/pollution, (g) plate tectonics and continental drift, (h) geologic time, (i) the Moon, and (j) atomic structure.

The curriculum has been adapted using activities I have developed. I write a handful of new activities each year and revise all activities after each unit. When I first moved to inquiry, the idea of a major overhaul of my activities was overwhelming. I decided to do a handful each year until I had moved all of them to an inquiry approach. I revise all activities after each unit because I have learned from my observations of students doing activities that there is always something that I can fine-tune. If students are asking me to clarify what I have asked on an activity, I realize I need to improve the question(s). A recent addition to the activities has been the "I think" questions that offer information on student preconceptions and experiences. Most of these activities can be done with a limited budget.

The textbook is used solely as a resource, rather than a way to disseminate science knowledge. The activities include references to pages of the textbook for students to easily look up information. I go to journals, the internet, and colleagues for ideas. Students also have the internet as a resource available to them. I believe the teacher is the most important resource to the students as they develop the skills of learning.

Focusing on Student Understanding, Use of Scientific Knowledge, Ideas, and Inquiry Processes

The daily overview of concepts and the investigations the students carry out are the first step in developing student understanding. Students complete portfolios that contain an overview

Figure 2. Excerpt From Curriculum Maps

	Sixth-Grade General Science **Simple Machines**
Essential Questions	What are examples of simple machines? Why can't a simple machine be 100% efficient? What are 2 things that must occur for work to be done? How does a machine make work easier?
Concept	Six simple machines – lever, pulley…. Properties of simple machines. Forces (friction, gravity, drag, and motion). Work. Newton's first law. Application of concepts – Balloon cars.
Skills	Works in a cooperative atmosphere. Generates questions and makes predictions. Executes procedures based on inquiry. Makes observations, collects, interprets, organizes, and explains data from graphs & tables, draws conclusions, and communicates results. Uses appropriate instruments to obtain data. Analyzes data & recognizes patterns. Applies what is learned to real world situations. Applies knowledge of safety and use of equipment.
Assessments	Identifies simple machines. Identifies the properties of a simple machine. Identifies the affect of forces on the ability to do work. Designs, constructs, and evaluates performance of a balloon car (rubric). Develops a written plan to construct a balloon car. Makes scale drawing of balloon car, complete with measurements (rubric). Practical lab exams. Portfolios.
Activities	Investigate friction. Investigate wedges, screws, and incline planes. Investigate wheel and axle. Investigate 1st, 2nd, and 3rd class levers. Investigate fixed, belt, and moveable pulleys. Worksheets. Design, construct, test, and race a balloon car. Balloon car problem and solution worksheet. Balloon car journal.
Resources	Textbook as a resource. Structured inquiry activities developed by teacher. Balloon car rubric.

Figure 2. Continued

	Seventh-Grade Earth Science Earthquakes
Essential Questions	What causes earthquakes and volcanoes? Why wasn't the theory of plate tectonics accepted until the 1960's? How can an earthquake be felt in Iowa?
Concept	Earthquakes, volcanoes, and tsunamis. Richter scale and seismology. Continental drift and plate tectonics. Pangaea and Eurasia. Sea floor spreading, trenches, and subduction. Earth's crust, mantle, and core. Faults.
Skills	Works in a cooperative atmosphere. Generates questions and makes predictions. Executes procedures based on inquiry. Makes observations, collects, interprets, organizes, and explains data from graphs & tables, draws conclusions, and communicates results. Uses appropriate instruments to obtain data. Analyzes data & recognizes patterns. Applies what is learned to real world situations. Applies knowledge of safety and use of equipment.
Assessments	Recognizes areas of earth that have earthquakes & volcanoes. Explains causes of earthquakes and volcanoes. Describes the theory of continental drift and plate tectonics. Explains how fossils and rock support the theory of continental drift. Describes different forms of faults. Locates major plates on earth and ring of fire. Plots earthquakes and volcanoes. Practical lab exams. Portfolios.
Activities	Investigate earthquakes and volcanoes. Investigate continental drift. Investigate mountain ranges. Investigate interior parts of earth. Investigate faults. Investigate density.
Resources	Textbook as a resource. Mt. St. Helens video. Plate Tectonics video. Earthquakes video. Structured inquiry activities developed by teacher.

drawing of the unit they complete. Following that is a prediction each student makes about the question I have given them. Data tables are included in the portfolio, followed by the conclusion. The portfolios are one way I am able to determine their level of understanding. Additionally, the questions I ask as I walk around the room while they do the investigations give me a clear idea of their understanding. Finally, the class sharing and discussion at the end of the investigation give me a clearer picture of their understanding of the concepts for the day, as well as their ideas and understanding and use of the inquiry process.

Guiding Students in Active and Extended Inquiry

The manner in which I have developed the activity sheets is the first way in which I guide the students in inquiry. My practice of answering their questions with questions of my own is a means of guiding students and making me a facilitator of learning. This is often frustrating to the sixth-graders when they first come to my class. I have often heard "Don't ask him a question, because he just asks you one right back." I have learned there are four types of questions that are successful in guiding students as they carry out investigations. These questions serve to

1. Clarify: Can you be more specific?
2. Focus: Can you give me an example?
3. Probe: What do you think will happen?
4. Prompt: What can you do…?

It took me a while to develop this questioning skill, but it is necessary for an inquiry approach to teaching. I needed to immerse myself in inquiry to be able to teach as an inquirer. Being a facilitator means helping students to learn to think critically and logically, and to develop the relationships between evidence and explanations.

The summary discussions where I ask why differences in results may have occurred are a further step in guiding the students. Extended inquiry occurs with select units; for example, a weather unit has students collecting data over a 30-day period. Special projects have students carrying out activities and doing data collection and analysis over a two- to six-week period. Some activities, such as a solar car activity, build on their previous study of magnets, electricity, simple machines, and alternative energy. The solar car activity truly applies all they have learned in the previous units. Imagine how exciting it is to hear this student dialogue: "My car goes in reverse. I have to rebuild it." "No, you don't. Remember…"

Providing Opportunities for Scientific Discussion and Debate Among Students

At the end of the activity, the sharing of findings by each student with the entire class provides opportunities for discussion and debate. As students carry out the investigations, they often check with other groups to see what they are doing and why. Collaborative learning is occurring.

Continually Assessing Student Understanding

Assessing understanding is key to the educational process in my classroom. Through observations made as I walk around the classroom during investigations, answers to my questions, and class discussion I am able to determine what I may need to provide in my classroom summary at the end of the activity. For some projects, I have developed a rubric that students complete. A *balloon car* rubric is an example (Figure 3): each student evaluates the car they have developed, providing information on what common problems may be and how to correct the problems.

Figure 3. Excerpt From Balloon Car Rubric

Grade A:
All of the following conditions are met:
1. Balloon powered car travels at least 10 feet.
2. Car has extensions that make the car longer or car has an extension to support the balloon. Wider axles do not qualify as extensions.
3. One set of wheels turns together with the axle (dependent) and the other set of wheels turns on the axle separately and independently.

Grade B:
Condition 2 or 3 from Grade A is met and the car travels 6–9 feet.

Grade C:
1. Car travels between 2 and 5.9 feet.
2. One set of wheels turns on the axle and the other set turns with the axle.
3. No extensions for wheels or balloons are present.

Grade D:
1. Car travels 1.9 feet or less.
2. Grade C conditions are not met.

Grade F:
1. No car is made or brought to the race.

All cars must have at least three wheels. If the car has only three wheels, the pair of wheels must turn separately.

Supporting a Classroom Community With Cooperation, Shared Responsibility, and Respect

On average, 60–70% of the time I ask students to share aloud their answers to the "I think" questions. Students understand there is no wrong answer. No one says, "That's dumb," or makes any negative comment. Indeed, students often find there are common threads in their answers to the "I think" questions. This is a time when the group shares an expectation for respect so that we can learn from each other.

Collaborative learning is another example of cooperation in the classroom. I have developed a system whereby students work in pairs for each investigation. The pairings change every week, eliminating the self-grouping with friends that often occurs in school. This also eliminates the feeling of being left out that the students chosen last often feel. At the beginning of the year, I develop a table with each student's name. Each name has a number. The weeks of the school year are across the top of the table. Students can easily see the number of the student they are working with for the week (Figure 4).

Figure 4. Example of Assigned Lab Partner Sheet for up to 24 Students

Week	1/1	1/8	1/15	1/22	1/29	2/5	2/12	2/19	2/26	3/4	3/11	3/18
Name	1	2	3	4	5	6	7	8	9	10	11	12
1.	23	24	2	3	4	5	6	7	8	9	10	11
2.	22	23	1	24	3	4	5	6	7	8	9	10
3.	21	22	23	1	2	24	4	5	6	7	8	9
4.	20	21	22	23	1	2	3	4	5	6	7	8
5.	19	20	21	22	23	1	2	3	4	5	6	7
24.	12	1	13	2	14	2	15	4	16	5	17	6

Understanding and Responding to Individual Students

Answers to the "I think" questions draw upon student experiences and interests. The group sharing helps me understand the baseline they are coming from. This helps me focus my questions when I go around during the investigation.

More Emphasis on Assessment Standards

Assessing Scientific Understanding and Reasoning

Through the investigations, the portfolio summaries, and classroom discussions I am able to develop a clear picture of student understanding of scientific understanding and reasoning. Twelve years ago, I developed the idea of the students completing portfolios (a summary of each investigation). In the portfolios, the students record their Plan of Attack (POA). The POA includes (a) answers to "I think" questions; (b) "Questions I have" developed by the student; (c) their procedure (what they are going to do); (d) a data table; (e) a conclusion; and (f) where appropriate, an application section. I have learned the importance of reflective writing, and am able to see growth in their investigative skills as they practice inquiry and write activity summaries in their portfolios.

Assessing to Learn What Students Do Understand

I use a variety of assessments and have them specified on the curriculum maps for each unit. Examples include: (a) identify translucent objects, (b) change the direction of a fan's blade, (c) draw and label simple schematic circuits, (d) construct an electromagnet, (e) write a report, (f) scale planets to size and distance from the sun, (g) design a solar car, (h) use a model to understand moon phases, and (i) complete practical lab exams. Unit tests and standardized tests such as the Iowa Test of Basic Skills also give me a picture of student understanding.

Students Engaged in Ongoing Assessment of Their Work and That of Others

Students assess their work as they listen to the group discussion at the end of an investigation where results are shared, reasons for differences are discussed, and possible alternative activities are identified. Additionally, for select projects they complete a rubric that assists them in evaluating their projects. For a solar car project, each student critiques one other student's solar car according to a rubric. In the process, students learn about concepts applied by a peer in the design of the car.

I have developed a self-report knowledge inventory for students who are challenged in learning (resource students, at-risk students, and self-contained and integrated [SCI] students). Students complete the self-reports (Figure 5) at the end of a unit as they think about their understanding of the unit's concepts. These students also take a revised version of the unit test.

Figure 5. Excerpt From Student Self-Report Knowledge Inventory

1. I have never heard of this.
2. I have heard of this but cannot do it.
3. I think I somewhat understand how to do this.
4. I can do this.
5. I can do this and can explain this to another student.

Add up to 5 words per statement to show you can do this if you score any a 4 or 5.
Add up to 2 words per statement to show you can do this if you score any a 3.
____Use a spectroscope
____Use an illustration to show the main sequence of stars
____Do investigations to show Newton's first law
____Do investigations to show Newton's third law
____Do investigations to separate visible light

More Emphasis on Content and Inquiry Standards

Understanding Scientific Concepts and Developing Abilities of Inquiry

The activities I have developed for the typical day include students discussing concepts, investigating the concepts, and learning vocabulary that helps them speak knowledgeably about those concepts. The reason I use *guided* inquiry as a teaching approach rather than *open* inquiry is that I believe some structured knowledge is necessary in order for students to be able to communicate scientific concepts. Including vocabulary in the investigations helps students begin to build and understand explanations for their observations. The names and "words to know" associated with the investigations become useful and meaningful. "Words to know," based on direct experience, results in understanding rather than memorization. One sees students' increasing comfort with inquiry in their portfolios as they go through the year. (I occasionally use worksheets to reinforce concepts.)

Learning Subject Matter Disciplines in the Context of Inquiry, Technology, Science in Personal and Social Perspectives, and History and Nature of Science

As students learn subject matter, we often discuss how what we are discussing in the classroom relates to the real world. Application is essential to helping them understand that science is a part of their everyday lives. Several units have an *environmental education* component, where we discuss the impact of inefficiency, pollution, and waste in light of what they mean to the students and to the world as a whole. Specific projects—on oil filters, lighting and water efficiency, and alternative energy—help them gain knowledge to make decisions for the future.

A science club offers students out-of-class time to explore a variety of interests. Since 1993, state and national awards have acknowledged students' numerous projects for their scientific process. Students also have the opportunity to carry out extended projects.

Technology is a part of the classroom as students (a) design solar cars and Lego rovers, (b) use digital cameras and digital microscopes, and (c) discuss how technology can help or hinder the concept under investigation for the day. We often use a "what if?" approach in discussing technology, including the benefits and other possible consequences.

History and nature of science are a part of the investigations. I have a growing number of activities where historical information is included and is part of the "I think" question(s) at the beginning of the activity.

Integrating All Aspects of Science Content

Through extensive use of investigations and a guided-inquiry teaching approach, students integrate science knowledge and the science process. When I hear students say "Sweet!" as they observe, or change how they are doing something with amazing results, I know they are tying knowledge and process together.

Studying a Few Fundamental Science Concepts

I have developed the curriculum for each grade to have 11–12 units. Essential questions/concepts are identified for each unit. Typically, there are four or five concepts we focus on for each unit. So, by the end of each year the students will have studied 48–55 concepts.

Implementing Inquiry as Instructional Strategies, Abilities, and Ideas to be Learned

The curriculum maps show the relationships between the essential questions/concepts, content, skills, assessments, activities, and resources for each unit. These really identify the strategies to used, the abilities or skills the students demonstrated, and the ideas (concepts) learned.

Activities that Investigate and Analyze Science Questions

Each investigation begins with a question the students will be answering. As they develop the investigation, they work toward understanding and the ability to answer the question. Group discussions enable the students to understand why differences in results may occur. My questions to them, such as "Why do you think…?" also help them analyze what they are seeing.

Investigations Over Extended Time

Not every investigation can be completed within one 45-minute class period. Some units lend themselves well to investigations over an extended period. The mineral unit is an example. The physical properties of minerals are studied over two weeks. Activities associated with a weather unit and simple machine unit occur over several weeks. Separate units build on each other, culminating in a project that incorporates learning from each in a final design.

Using Evidence and Strategies for Developing or Revising Explanation

Students use evidence (their observations and data) to develop conclusions, which are recorded in their portfolios. In the closure at the end of the class period, I ask students to share their findings and conclusions. There is class discussion, with a wide variety of explanations provided for some units. The class discusses why there are differences, and what variables or measurements in the investigation may have yielded the results. This is an opportunity for students to go back and do the investigation again, paying close attention to those variables or measurements.

Doing More Investigations

Eighty-five percent of the class periods are spent doing investigations; follow-ups help develop understanding, ability, values of inquiry, and knowledge of science content. The frequency with which students do investigations helps them develop the ability to work through the scientific process with ease. It becomes second nature to them for two reasons. First, repetition strengthens learning. Second, investigations are an exciting way to learn and provide a needed break from the textbook and worksheet learning that commonly occurs in other classes.

Public Communication of Student Ideas and Work to Classmates

The students share answers to their "I think" questions aloud with the group 60–70% of the time. This helps students see where they have common thinking and how an idea may be put to the group that someone else has not thought of. Public sharing also occurs at the end of the investigation, when students share with the class what they have learned in the investigation. Additionally, these students have shared projects with the School Board, City Council, and at state, regional, national, and international conferences.

Communicating Science Explanations

Students communicate findings in the closure at the end of the class period. As they do so, they share findings and thoughts as to why the results occurred. In addition, students have done presentations to parents at Open Houses for parents. Students take their parents through the same investigations they have done in the classroom during the day, explaining what they have learned.

Applying the Results of Experiments to Scientific Arguments and Explorations

In the closure time as students discuss their findings, they discuss their findings in relationship to the concept(s) I introduced at the beginning of the class period. Additionally, in my summary I share with the group what the students observed and how this supports (or does not support) the concept(s) being covered in this unit.

Evidence Learning Is Occurring

Assessments within my curriculum help to determine student understanding and abilities, monitor student progress, and collect information to grade student achievement. The traditional assessments I use include practical lab exams, unit tests, and the Iowa Test of Basic Skills (ITBS). The latter is a standardized test students take in the fall of each year. Science is one component of the

ITBS. Over the past 16 years, I have seen the results vary from year to year and class by class. The data yielded from implementation of the *More Emphasis* conditions of NSES show the same unsystematic variability, but continue to show that learning is occurring (Figure 6). Creativity and problem solving are difficult to measure using these standardized tests.

Figure 6. Iowa Test of Basic Skills Results Over Time for Students in My Classroom

Activity Related to NSES *More Emphasis* Conditions	Year and National Percentile Rank of sixth graders—test taken in the fall before these incoming students have had much introduction to my teaching approach and assessments		Year and National Percentile Rank of seventh graders (previous year's sixth graders)—these students have now had a full year exposure to my teaching approach and assessments		Year and National Percentile Rank of eighth graders (previous year's seventh graders) – these students have now had two full years' exposure to my teaching approach and assessments	
	Year	Rank	Year	Rank	Year	Rank
1991: Six units per grade use an inquiry approach	1991	91	1992	92	1993	85
1993: Three-fourths of the units per grade use an inquiry approach	1993	89	1994	74	1995	78
1995: All units use an inquiry approach	1995 1998	73 60	1996 1999	69 43	1998* 2000	67 90
1999: Implemented the Plan of Attack portfolios, group discussion of results of investigations	1999	67	2000	94	2001	65
2000: Developed curriculum maps for each grade, focusing on activities, assessments, skills, and essential concepts/questions for each unit	2000	81	2001	79	2002	90
2001: Added historical information to investigations along with "I think" and "questions I have" to investigations. Continued to refine the *More Emphasis* teaching, assessment, content conditions used in the classroom	2001 2002 2003	77 81 91	2002 2003	94 83	2003	87

*Test not taken in fall 1997.

Other evidence of learning is found in the portfolios, which show (a) student understanding of the question of the day, (b) procedures to answer the question and (c) conclusions. I see increased use of the scientific process, creativity in how students develop the Plan of Attack, and comfort with the "I think" portion of the portfolios. The observations I make as the students carry out their investigations, along with the responses they make to my questions, also show student understanding.

Students completed an entry survey as they entered sixth grade in 2003 and did so again at the end of the school year (spring 2004). The survey explored general attitudes toward science and science classrooms, with students using a Likert scale to indicate level of agreement or disagreement. For the 2003–04 school year these surveys showed no change between pre- and post-responses to the statement "I enjoy designing and conducting experiments." The post-survey showed a 17% increase in the number of students marking *strongly agree* or *agree* to the statement "I often test my own hypothesis." The post-survey showed a 9% increase in the number of students marking *strongly agree* or *agree* to the statement "I like classes that encourage me to discover some ideas for myself." Finally, the post-survey showed a 10% increase in the number of students marking strongly agree or agree to the statement "I learn well by problem solving with a lab partner." One may ask whether a survey of student attitudes is evidence of learning, yet the results clearly show attitudes changing for the three measures. Student attitudes are an important piece of the foundation required for learning; I believe the number of students in Science Club shows a growing interest in science and use of the scientific process in exploratory activities. Over the past few years, teams of students have submitted a number of projects for award consideration. In 2003–04, 25% of my students worked on special projects. Students have received a number of awards. Judges at the state, regional, or national level evaluate these projects or award applications. The success of the students is evidence that learning is occurring, albeit in the Science Club as compared to the classroom. Yet, skills they learn in the classroom transfer to these projects.

Awards Won by West Branch Middle School Science Students

- 2004: Region VII EPA National Award
- 2004: President's Environmental Youth Award
- 2004: eCYBERMISSION finalist environmental awards
- 2003: Second place, National eCYBERMISSION environmental awards
- 2003: Semi-finalists in Bayer NSF Community Issues Award for Region 3
- 2002: Semi-finalists in Bayer NSF Community Issues Award for Region 3
- 2002: Governor's Environmental Excellence Award: Waste Management
- 1999: Semi-finalists in Bayer NSF Community Issues Award for Region 3
- 1999: Student selected as Youth Conservationist of the Year in Iowa
- 1997: Region VII EPA National Award
- 1997: President's Environmental Youth Award
- 1997: Two sixth graders represented Iowa at the first National Solar Car Races in Dallas, Texas. (This team finished tied for third in the national races.)
- 1996: Student selected as Youth Conservationist of the Year in Iowa

In addition to these examples of learning, the student quotes at the end of the solar car unit point out the benefits of the inquiry approach and use of the *More Emphasis* approach:

"Never before have I ever learned about building a car, conserving energy, using different forms of energy, working as a team, experimenting, and problem solving all at the same time!"

"Many kids don't remember stuff they are forced to learn out of a book. But we will remember building solar racers and how they worked."

"The project allowed us to see the real thing happening. We weren't just reading about how solar panels make electricity. We were actually applying the ideas and making it happen."

"When you read it out of a book it is harder to understand than when you do it yourself. You have questions that you actually can see have a purpose."

"If you build a car and it runs, you end up getting sucked into learning why it works. You end up looking things up because you want to learn."

"You get to see why it is good instead of someone telling you this is how it works."

"We had to be creative, use our ideas, and work together."

"I learned how to make designs and overcome problems."

"Working as a team played an important role in the success of our car."

Learning is occurring.

Summary

Students are active learners in my sixth- and seventh-grade science classes. Guided inquiry enables them to learn content as they carry out investigations—an almost daily activity. Student achievement is higher when both the concrete content and the inquiry investigations are a part of the science classroom. The inquiry approach increases student creativity, problem solving, independence, curiosity, and favorable attitudes toward science, school, and learning. The program is successful, as demonstrated by discussions following investigations, by student involvement in Science Club and award-winning projects, and by traditional testing methodology.

Science is an important component of everyday life. I believe that students learn best through process. If one stresses content, one forces students to memorize for that lesson. By teaching the process of learning (including problem solving skills, creativity, and critical thinking skills), students will learn for a lifetime. To be able to question, explore, and problem solve leads to lifelong learning.

References

Ibarra, H. 1998a. Add inquiry-based learning to your science curriculum. *Middle Ground* 2: 31–33.

Ibarra, H. 1998b. Balloon-powered cars. *Science Scope* 22 (3): 21–23.

Ibarra, H. 2001. *Learning without limit—Solar powered racers: Racing with the sun.* Tampa, FL: Showboard.

Llewellyn, D. 2002. *Inquire within: Implementing inquiry-based science standards.* Thousand Oaks, CA: Corwin Press.

National Research Council (NRC). 1996. *National science education standards*. Washington DC: National Academy Press.

National Research Council (NRC). 2000. *Inquiry and the national science education standards: A guide for teaching and learning.* Washington DC: National Academy Press.

Rakow, S. ed. 1998. *Pathways to the science standards—middle school edition.* Arlington, VA: National Science Teachers Association.