Exemplary Science in Grades 9–12

Standards-Based Success Stories

Robert E. Yager, Editor

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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* (currently available); *Exemplary Science in Grades 9–12* (the book you are reading); *Exemplary Science in Grades 5–8;* and *Exemplary Science in Grades K–4* (the latter two books are in development.)

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 high 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.

The NSES goals were meant to frame the teaching, staff development, assessment, content, program, and system efforts as visions for change and reform. These goals represent a step beyond those central to Harms' earlier Project Synthesis. The four goals (justifications) for K–12 science listed in the NSES encompass preparing 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).

Basically, the goals do not suggest any content or any glamorized process skills that must be transmitted or experienced for their own sake. Paul Brandwein has called for teachers and schools to ensure that each high school graduate have one full experience with science (1983). He suggested that this would create a revolution in science education—something we still badly need. Some NSES enthusiasts suggest that one such experience each year would be a better goal during the K–12 years—a 13 year continuum of science in school—and perhaps one each 9-week grading period would be an even better goal!

The NSES volume begins with standards for improved teaching. That chapter is followed by chapters on professional development, assessment, science content, and science education program and systems. Content was placed in the document after the other three for fear that placing it first would invite a focus only on what should be taught—almost relegating teaching, staff development, and assessment to "add-on" roles. The major debates, however, centered on what should appear in the content chapter.

NSES and Science Content

A major direction in the NSES with respect to content was the identification of eight facets of content. These facets change the focus from a traditional discipline focus with a list of major concepts under each discipline, to a much broader listing that is more indicative of the goals (justifications) for science in high schools. These eight facets of content elaborated in NSES are

1. Unifying Concepts and Processes;
2. Science as Inquiry;
3. Physical Science;
4. Life Science;
5. Earth and Space Science;
6. Science and Technology;
7. Science in Personal and Social Perspectives; and
8. History and Nature of Science.

Just as the first NSES goal is considered the most important one, the first facet of content (Unifying Concepts and Processes) is similarly considered the most important. It was envisioned as being so basic that it was first thought to be included as the preamble for each content section of NSES. However, many felt that too many would simply move to a new listing of basic discipline-bound concepts and ignore the preamble. Although life, physical, and Earth/space science still appear, some lists combine them into a listing of basic science concepts as a single content focus—thereby suggesting a more integrated approach to the major concepts comprising modern science. Major debates occurred in identifying these eight content constructs and the specific content included in each of the "discipline-bound" content areas.

Important current reforms must focus on the four less familiar content facets, namely: (a) science for meeting personal and societal challenges (referring to goals 2 and 3); (b) technology—which now enjoys a whole set of standards produced by International Technology Education Association (ITEA 2000); (c) the history and philosophy of science; and (d) science as inquiry.

The *More Emphasis* conditions for inquiry represent what the current reforms are all about and indicate why the use of social issues is considered essential. The *More Emphasis* conditions for inquiry are meant to reverse the failures in 1981 in finding examples of teaching science by inquiry in U.S. schools. After the Project Synthesis report, Paul DeHart Hurd (1978) reported:

> *"The development of inquiry skills as a major goal of instruction in science appears to have had only a minimal effect on secondary school teaching. The rhetoric about enquiry and process teaching greatly exceeds both the research on the subject and the classroom practice. The validity of the enquiry goal itself could profit from more scholarly interchange and confrontation even if it is simply to recognize that science is not totally confined to logical processes and data-gathering." (p. 62)*

Issues related to student lives, their schools, and their communities can provide the contexts that invariably require the concepts and skills that appear in science programs in typical schools.

However, instead of starting with a high school curriculum and proceeding through it, the student is more central and becomes the magnet for the need for what is generally taught. To many students it seems that the typical science content has been dictated by teachers or textbook authors who merely assume its relevance for all learners. Generally, everything is taught "because it will be useful—trust me!" But, for most students such use is never found. Instead science content is seen only as something useful to those who wish to pursue college/university study, especially in medicine, health sciences, and engineering—and also important for performing well on college entrance examinations. It can be argued that our major problem with high school science remains: science is viewed as merely a stepping stone to further study of science at the next level, whether grade by grade in schools or for the college track in high school and for college entrance. It is not seen as something important and useful for *all*.

The NSES broaden the focus to something other than a consideration of the concepts that characterizes biology, chemistry, physics, and to a much lesser extent, the Earth/space sciences. It also includes technology (the human-made world) as well as a focus on the objects and events in the natural universe. Moreover, it includes society, which is easy for life science enthusiasts since it represents a level of focus in biology (i.e., ecology). It is also related to the social studies (such as sociology, economics, government, geography, and psychology).

However, it is insufficient to assume a universal understanding of science itself. To most persons, science is what is studied in school. What is studied usually ends up as topics or chapters organized around precise concepts that are traditional features of textbooks, and often coincide to courses in college departments where science teachers have had direct experience as students during their preparation.

Science needs to be understood and seen as appropriate for all—as a human endeavor that all people can understand, experience, and use. The NSES goals exemplify a holistic view of science. Carl Sagan emphasized a vital point when he observed that every human starts as a scientist (NRC 1998). However, as the child grows and attends school, he/she is discouraged from practicing real science and is taught skills in science classes that are alien to science itself. Science consists of four essential features—all of which should be a part of school and every child's experience:

1. Asking questions about the objects and events observed in the natural world;
2. Proposing answers (possible explanations) to these personally constructed questions;
3. Designing tests or preparing logical reasons to establish validity for the proposed answers; and
4. Communicating the question, proposed explanations, and the evidence assembled to support the explanation to others (especially others, who have pondered and investigated similar objects and events in nature).

Science is a human endeavor that is characterized by curiosity and wonderment, by attempts to explain, by the desire to determine the accuracy of each explanation advanced, and by responsibility for sharing and communicating the process to others (in science at the research level, this means to others constituting the science establishment). If science were advanced with this four point sequence, goal one of NSES would be met. Yet it rarely occurs and remains a major issue in science education, especially in high school and college programs. The question arises: how would real science *ever* be offered in a textbook, a teacher's lecture, or a state framework? For complete science is what current reforms are all about—and science for all!

Conclusion

The fifteen high school exemplars all show great progress for implementing the Standards and the stated goals for science in grades 9–12. 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 high 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 fifteen 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.

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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.

It's the "Little Things" That Can Change the Way You Teach

David L. Brock
Roland Park Country School

Setting

My school is an urban college preparatory school for girls, located in Baltimore, Maryland. An independent school, we teach grades K–12, and in our high school division we currently have 284 young women in grades 9–12, with a 35% minority enrollment, 21% of them receiving financial assistance. Our typical class size in the sciences is between 18 and 20 girls, and classes meet for three 70-minute periods each week in an alternating "A-day/B-day" block schedule. In the 2000–01 school year, we completed construction of a new science wing in accordance with the national recommendations for size and pupil number in combined lab-lecture rooms (Biehle, Motz, and West 1999). Among other renovations to the building at that time, we became a laptop computer school with a wireless network for all students grades 7–12 (with a separate dedicated computer lab for K–6). While our science program is a required academic component of all K–12 grades (including biology, chemistry, *and* physics in the high school), the specific program I will be discussing here—"The Little Things That Run the World"—is only part of the ninth-grade honors biology course.

Changing the Classroom's Quality

This program emphasizes the "student-as-player/teacher-as-coach" approach to the classroom (NRC 1996). A student-centered curriculum, it provides a model for the teaching standard on how to guide students through an extended, focused scientific inquiry, where students bear the primary responsibility for their learning. Because the project requires regular drafts of students' pre-lab research, experimental protocols, data charts, graphs, and mathematical analyses, it also provides a model for the assessment standards with respect to examining ongoing student work with a view to helping them gain a steadily richer understanding of both their topics and their investigative skills (NRC 1996).

During "Little Things," each team of students chooses, performs, and manages its own experimental investigation into a focused topic in the ecology of soil microbes (e.g., "What impact did a recent drought have on protozoa levels?"). Thus, the project provides a model that emphasizes *all* of the National Science Education Standards' (NSES) preferred content standards for the life sciences (NRC 1996). But even more important is the fact that, as a result of participating in field study projects like this one, students walk away from the experience with a richer understanding of humanity's place in the web of environmental relationships as well as the knowledge of their own power to understand the intricacies of the natural world. Since this kind of wisdom is ultimately what any of us who teach science are all about in the first place, projects like "Little Things" can help all of us come closer to the "spirit" that lies at the heart of the all good science education.

Who We Are

My students and I have been running "The Little Things That Run the World" project since the 1999–2000 school year. Originally part of our school's involvement in the NSF's Baltimore Long-Term Ecological Research Study (BES), it has evolved over the past four years through my involvement with the Paul F. Brandwein Institute (Brock 2002), and has generated considerable funding interest during its four years, including grants from the Toshiba America Foundation, the Captain Planet Foundation, and the ReliaStar/Northern Life *Education's Unsung Heroes* program. It continues to serve as the culminating end-of-year exam for my ninth grade honors biology students, and several of its alums have gone on to participate in the school's science research seminar, and publish related work. "Little Things" has even led to the creation of a three-week summer research internship—the Environmental Science Summer Research Experience for Young Women—that just completed its third successful year. In the spring of 2003, the program was honored with the Gustav Ohaus Award from the National Science Teachers Association (NSTA).

The Program

The "Little Things" project is a unique curriculum unit on the soil ecology of microbes that has five major goals:

- to provide students with the opportunity to engage in real scientific research where none of the answers are known ahead of time and in so doing present them consequently with the chance to develop their own hypotheses, to design and perform their own experimental protocols, and to analyze and evaluate their own results, submitting them for peer review and to various community stakeholders;
- to give students the chance to learn how to work with, identify, and estimate

populations of diverse, unknown microbes using standard microbial research techniques and technologies;

- to develop in students an understanding of the biochemistry of soil microbes and their immediate micro-environment (pH, temperature, humidity, etc.);
- to generate in students a comprehension of the role microbes play in the overall health of the soil and its ecosystem and how they influence and interact with the multicellular organisms of that system (e.g., invertebrates, plants, etc.);
- and, finally, to cultivate in students an appreciation of how human uses of the soil (e.g., as playing fields, gardens, etc.) impact the viability of soil microbes and, hence, of the greater soil ecosystem itself.

During the five weeks of the project, students work in independent research teams of three to four members, on research topics of their own choosing, and with the provision that it must have something to do with how our school's use of the campus grounds might be impacting soil ecology. Each team starts by finding information on the role(s) of various microbe populations in the soil using internet and library resources (Figure 1) until they have learned enough about what microbes are doing in the soil to begin narrowing their focus to a specific interest (e.g., the role of protozoa in the soil food chain). From this focus, students then start to develop a specific experimental question related to the fields, grassy areas, and woodlands on our school's campus (e.g., "What impact does the chalk used to mark the lines on the lacrosse field have on the density of bacteria living in that soil?"). Finally, they use the knowledge from their research to generate a specific hypothesis and begin to design their experiments.

Figure 1: Performing Background Research

Throughout the year, the students have already had to generate almost every one of their controlled experiments from scratch, determining the specific steps they will take, what their controls will be, and so on. Hence, experimental design itself is something with which they are quite familiar. However, to accomplish this task during their project, they first have to learn some basic, standard methods for studying soil microbes, methods with which most of them are initially unfamiliar (Hall 1996). Therefore, while they are working on their background research at the start of the project, they are also learning how to use augers to take soil samples, how to perform serial dilutions and soil saturations to extract microbes for analysis, and how to operate soil analysis test kits (see Figures 2 and 3). Also, once the students begin working on the design phase of their experimental protocols, they have access to a professional soil microbiologist (through the project's original participation in BES), who comes in for one day during the early part of "Little Things" to consult with each research team on their individual investigation (see Figure 4). Thus, in spite of the practical challenges that come from studying soil microecology, the students in this project are able to achieve the necessary mastery of some rather sophisticated research strategies and procedures in a relatively short period (about two weeks).

Figure 2: Learning Lab Activities

Figure 3: Learning Lab Activities

Figure 4: Consulting with Scientists

Furthermore, they are doing all of this research and design in an educational climate of continuous assessment and feedback. Throughout the preliminary stages of their investigations, the student teams must submit a minimum of four regular, written updates about the progress of their inquiry for formal evaluation. Each time, the students learn additional questions they need to answer about their topic and about ways to improve their experiments, and with each submission and each new trial of an experiment, they receive the necessary pragmatic encouragement and support they need in order to discover how best to achieve their individual team goals. Students may submit these updates for formal feedback *more* often than is required, but regardless of how often they do so, they must demonstrate an increase in the level of intellectual rigor with each update submitted; in this way, they come to understand that learning (about science, or, for that matter, anything else) is always about stretching one's understanding.

The consequence of all of this ongoing appraisal, research, and experimentation is that, if you were a fly on the wall during "Little Things," what you would see is active young women simultaneously exploring the internet, plating serial dilutions, testing for inorganic nutrients, peering through microscopes, quantifying microbe densities, and a whole host of additional possible activities (see Figure 5). You would see their teacher roaming the room, coaching and prompting, using informal discussions to evaluate and guide, but the real teaching and learning—and, most importantly, the *responsibility* for it—would reside with the students. They themselves attain the objectives described above, and what they accomplish each year can be truly amazing. Recent projects have included everything from an examination of the impact of different soil aeration methods on protozoa (see Figure 6) to a study of which method of restoring disturbed areas following the construction of the science wing (e.g., sodding versus seeding) returned microbe levels to healthy levels the fastest (see Figure 7). Each spring brings new challenges and new ideas, and what their young minds come up with in a given year is eagerly anticipated.

One other thing students learn by the end of this project, though, is that real research is never done in a vacuum. It is always submitted to peer review, critique, and to verification and substantiation. Consequently, the students who participate in "Little Things" must present their findings in the form of a formal research paper (including graphs and analysis of their data)—the best of which the class decides to post to the project's website for others to read and evaluate—and each team must present their findings to their peers, other teachers, and the administration during a class colloquia at the program's end (see Figure 8). The best are also posted to the project's website, and everything is updated each June to reflect the work of a given year.

Alignment With *More Emphasis*

Clearly, as challenged in the content standards of the NSES, engaging in a project like this one allows one to emphasize understanding a "few fundamental science concepts" about ecology (e.g., the impact of the microbial food chain on the health of the soil) versus knowing random definitions (like "food chain"), and it allows students to learn those concepts within the framework of an inquiry that has ramifications for decisions our community makes (e.g., Should we fertilize?). Furthermore, as explicitly challenged in the 9–12 Content Standard A, it involves implementing an inquiry that allows students to learn about the process itself as they pursue and analyze an actual scientific investigation over an extended period of time, learning multiple process skills within a specific context. The program also requires students to manage ideas and information in order to generate a complex argument that explains what the students discovered, and to apply this argument in communicating to their peers and others the consequences of what they found.

Figure 5: Counting Microbes

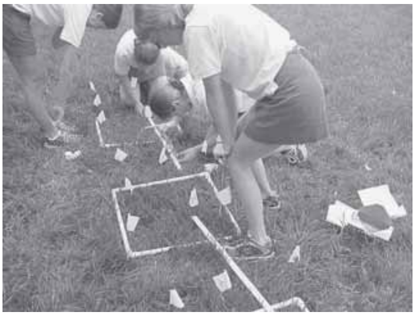


Figure 6: Setting Up Research Plots

Figure 7: Studying the Effects of Soil Restoration on Bacteria

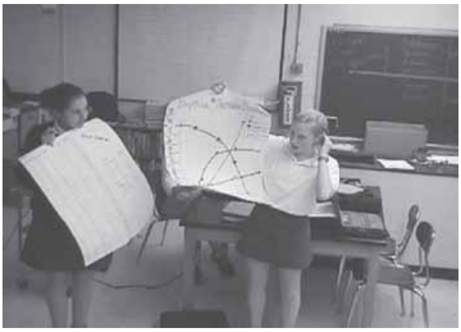


Figure 8: The Final Presentation

To see how "Little Things" can accomplish these things, let us look briefly at some excerpts from a final report a student team submitted this past year. They began their project by examining the role of nitrogen in ecological systems, and during the course of their background research, they found that:

- *… All life requires nitrogen compounds in order to live because nitrogen is an element that everything living must have to make proteins and DNA (Johnson 1998). Nothing can live without DNA or proteins. DNA copies itself into RNA, which makes proteins. Proteins cause chemical reactions that cause the chemicals of the cell (lipids, carbohydrates, water, proteins, and nucleic acids) to react between each other. These chemical reactions are how the cell performs its four tasks: reproduction, manufacture of chemicals, respiration, and synthesis.*
- *Air, which is 79% nitrogen gas, is the major reservoir and most abundant source of nitrogen (Nitrogen Cycle 2001). However, most organisms, including plants, cannot obtain nitrogen from the air. And as stated before, everything needs nitrogen to live. Plants must secure their nitrogen in "fixed" form, such as nitrate ions, ammonia, or urea (Nitrogen Cycle 2001). Plants convert nitrogen into a form that they can use through a process called Nitrogen Fixation (Nitrogen Cycle 2001). This is where bacteria come into play…*
- *… Fertilizer has the number one effect on plants, soil, and microbes. The nutrients and chemicals that fertilizer consists of alter the soil composition and thereby affect everything that relies on, or works for soil ... by using fertilizer the nitrogen cycle is modified because of the input of nitrogen quantity (from the fertilizer), hence, having an effect on the bacteria by giving them more "food" to perform their job in the nitrogen cycle...*
- *… The purpose of our experiment is to determine whether adding additional fertilizer to a plot of soil will increase or decrease the density of bacteria in that plot and also have an effect on the soil composition, especially the nitrogen cycle. We will see if different concentrations of fertilizer have a different effect on the total number of bacteria along with the nitrate level in the soil ... also, by performing our experiment we hope to see what particular impact humans carelessly have on the microbe environment they rely on so much. People have little or no knowledge about microbes and how much they are needed in and for the human life, and by adding fertilizer to their grass they could really be hurting something very significant. We hope to draw many conclusions from our experiment.*

From the text, it is plain to see that by focusing on a single core concept in ecology, the students were better able not only to learn about the nitrogen cycle itself but to place this knowledge within both the larger body of biology (i.e., the "value" of nitrogen in the fundamental biochemistry of living things) and an important social context (i.e., the school's decision to fertilize our grounds). A key idea in life science stopped being merely an abstraction for them and became part of an understanding they could apply in a way that had valid meaning for them *and* simultaneously demonstrate a richer understanding of important and significant scientific knowledge. Or, to put it another way, not only did this specific project enable students to achieve and demonstrate mastery of NSES 9–12 Content Standards, it allowed them to do so in ways that changed their paradigms about the world as well as their knowledge of it.

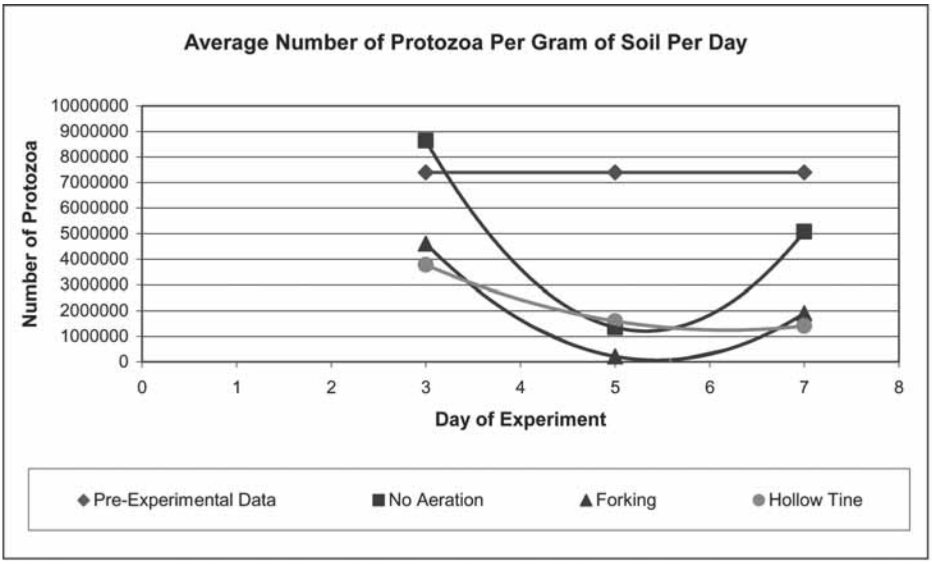
What is more, when students in a situation such as this one are able to perceive and then develop an experimental investigation that requires them to apply new found understanding such as described, they become exactly the kinds of critical thinkers who can generate the kind of data seen in Figure 9 and the sort of following final argument called for in the 9–12 Content Standards:

- *…Through the various trials of our experiment, our group confirmed our hypothesis was incorrect. We stated that the No Aeration plot would have the most protozoa, the Hollow Tine [method of aeration] plot would have the least amount and the Forking plot [method of aeration] would be somewhere in the middle. The No Aeration plot did have the highest amount of protozoa; however, the Forking and Hollow Tine plots were so close in data that we cannot say definitely whether or not one was higher than the other...*
- *…Looking at the data and the similar patterns in both plots, our group concluded that there was not substantial enough difference in the amounts of protozoa to confidently say that the difference was significant, and not just the result of some counting problem or other source of error... Looking back at conditions on that particular day, we noticed that it rained an extensive amount, enough to make a big difference in our data and the levels of protozoa. This goes to show that different weather conditions are also a factor in determining whether or not aeration is a good idea. For instance, on Day 3 and Day 7, when the weather was clear, no aeration was obviously the best method in obtaining high levels of protozoa. However, on Day 5, when it was raining, aerating the soil actually proved helpful in maintaining protozoa levels. Between the two aeration methods, Forking is better when the weather is clear and sunny because there is less surface desiccation and therefore less water is evaporated out of the soil. On rainy days, Hollow Tine aeration is best because bigger holes in the soil lead to more water infiltration. Water is important to protozoa levels because they "swim" through the soil and therefore more water would make it easier to move and catch prey.*

It is complex arguments such as this one that are precisely what the NSES demands that we emphasize more in our classroom, and analysis like that in Figure 9 can only come from the implementation of a real investigation, using authentic research methods. Combine this evidence with the example from the nitrogen cycle research, and you can see why programs like the "Little Things" project can generate just the sort of learning we all want to be about in our classrooms.

However, projects like mine are about more than the NSES *content* standards, they are also about *teaching* and *assessing*. Hence, the other major challenges one can tackle using a program like "Little Things" are the teaching standards and assessment standards. First, this project enables teachers both to guide students through a continual appraisal of their progress during an extended scientific inquiry and to adapt this guidance to meet the needs, interests, strengths, and experiences of each team of students. In addition, it encourages informal discussion while they work on improving their experiments, helping them learn how to evaluate their own work through this process. So, for example, in a group whose research question was on the impact of mulch on pH and bacteria levels, the original list of potential variables to control consisted of: *how much soil is taken in sample, what samples are tested for, what kind of mulch sampled*; whereas after four weeks of discussion and feedback, the final list of potential variables the team of students finally understood needed to be controlled for consisted of: *time soil samples taken, amount of soil samples taken, number of times experiment is replicated, how much soil is taken in sample, what samples are tested for, where normal levels are taken, what kind of mulch sampled, flower bed in which mulch is taken from, date soil samples taken, where in plotted area soil sample is taken from, the*

Figure 9: Sample Student Graph



amount of soil from each sample used for the pH testing, amount of demineralized water used in pH testing, amount of soil flocculating reagent used in pH testing, amount of solution transferred to spot plate, which depression used on spot plate, amount of duplex indicator used in pH testing, whether you use the duplex indicator or another indicator first, amount of soil in culture tube, amount of sterile water in each culture tube, amount of water you remove from each culture tube to the next, amount of soil dilution placed in to nutrient agar plate, the level of soil dilution tested, type of agar used.

Second, such projects allow students to own the responsibility for completing the project and gain from it what they choose to invest in it (Teaching Standard B.1). Compare the concluding argument presented earlier with the excerpt that follows; the range of what is possible with "Little Things" becomes abundantly evident:

…From the data shown, we are able to conclude that our hypothesis was correct. PH affects protozoa population greatly. The graph which displays the correlation between pH and protozoa shows that as the pH values increase, it appears that the number of protozoa increases as well. The decrease in the protozoa population in Plot 2 is expected because Plot 2 was the experimental plot where we changed the pH deliberately by adding sulfuric acid. This was also the soil that had a lower pH. From the graph of pH vs. Protozoa, population we can see that the optimal range for protozoa levels is between 7.0 and 8.0. Since we did not collect data from the other end of the pH range, we cannot determine whether the optimal range is only between pH values of 7.0 and 8.0 or if there is another lower range as well.

Third and finally, a significant component of the project is a final presentation to peers and administrations. Therefore, it provides a chance for formal discussion of student findings as they present them to the larger school community. Given that another major component is the four required drafts, "Little Things" also plainly assesses whether students are achieving a rich, scientifically accurate understanding of a body of critical knowledge and whether they can reason effectively about its larger implications through the ongoing give-and-take that accompanies the regular submissions of student preliminary reports.

Conclusion

In the course of four years, more than 150 young women have successfully completed the "Little Things That Run the World" program, which promotes student understanding of the scientific research process and enhances the way students envision and understand their world, cultivating in them a sense of ecological stewardship. As project director, it is my sincere hope that by discovering for themselves "the little things that run the world," my students will learn first-hand how their cognitive skills uniquely endow them to wisely manage their fragile legacy and to walk away equipped to transform their lives, their communities, their society, and ultimately their world.

Please come visit us at our website at *http://faculty.rpcs.org/brocka*; just click on the "Little Things" link.

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