Reflections on Nine Years of Conducting High School Research Programs

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ABSTRACT

For 9 yr, I directed an environmental sciences research program for high school students, and for 4 yr, I directed a teacher research program focusing on composting. Through these programs, 10 to 20 high-ability students and four teachers conducted research under the guidance of Cornell scientists and participated in science enrichment activities over the summer. Whereas the students worked on a variety of environmental and agricultural research topics, the projects for the teachers were chosen because they could be adapted for use in high school classrooms. Through the student program, I gained insights into (i) recruiting minority, rural, and other underserved students; (ii) ensuring a quality research experience for high school students; (iii) ensuring that students have an in-depth understanding of the research process, including issues involved in sampling, data interpretation, and the relationship of science to wider societal issues; (iv) gaining support of university researchers for the program; (v) providing nonresearch science enrichment activities (related to teaching, ethics, and careers); (vi) ensuring that students feel comfortable and supported in the university setting; and (vii) building long-term sustainability of the program. The teachers conducting composting research adapted Cornell research protocols for use in their high school classrooms, thus further promoting research experiences for high school students. Teacher and student research programs will need to be combined with other efforts to meet the goals of the science education reform movement, which calls for every student conducting an independent research project before graduating from high school.

During the 1980s and 1990s, concern about the number of students going into the sciences, in particular minorities and women, pervaded the science education community (NSF, 1990). This concern prompted the National Science Foundation (NSF) to initiate the Young Scholars Program, which provided summer research opportunities for high-ability junior high and high school students from 1988 to 1996. Similar high school student research programs were funded through the USDA, state governments, private industry, and colleges and universities. More recent concern about broadening the impact of such programs to provide a larger group of students with the opportunity to conduct original research has led to the establishment of NSF-funded teacher and teacher–student research programs.

From 1989 to 1997, the Cornell University Department of Natural Resources conducted a Young Scholars Program entitled the Cornell Environmental Sciences Interns Program (CESIP). The program targeted high-ability high school students between their junior and senior years who may have had limited science enrichment opportunities, including minority students and students from small, rural high schools. Each summer, CESIP provided opportunities for 10 to 20 such students to conduct science research for a period of 6 wk. The students were placed individually on research projects being conducted by faculty members and their graduate students in the College of Agriculture and Life Sciences at Cornell. Students also participated in a number of activities designed to enhance their understanding of their specific research projects, as well as of the general nature of scientific research as conducted at universities. Additionally, CESIP included a number of science enrichment activities to broaden the students’ perspectives and to make them feel at home in a large university. The overall goal for the program was to enhance students’ understanding of the research process as well as to promote a sense of responsibility in conducting and teaching science.

During 4 yr of the high school student research program, my colleagues and I also conducted an NSF teacher research program. The high school science teachers conducted composting research alongside Cornell scientists in the Department of Agricultural and Biological Engineering; Department of Food Science; Department of Soil, Crops and Atmospheric Sciences; and Department of Plant Pathology. Composting was chosen as the focus for the teacher research because much of the composting research conducted at Cornell is logistically simple and involves inexpensive equipment, and therefore could be adapted for use in the high school classroom. Additionally, composting, because of its importance to issues of solid waste disposal and sustainable food production, is of interest to students searching for social relevance in science classes. The teachers participated in a number of activities alongside the student researchers (e.g., weekly research discussions) and offered support to students who encountered difficulties at their research sites.

The primary purpose of this paper is to share our 9 yr of experience in conducting a high school student research program in a university setting. In addition, we will present some reflections on our teacher research program, and on the role teacher and student research programs play in meeting the national science education standards (AAAS, 1993; NRC, 1996). The information presented here is based largely on my observations, which took the form of conversations with the research mentors, students, and program staff; conducting and observing discussion groups and workshops for the students focusing on various aspects of the research process; and analysis of evaluation forms completed by the students focusing on various aspects of the research process.

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Abbreviations: NSF, National Science Foundation; CESIP, Cornell Environmental Sciences Interns Program; SEM, science, engineering, and math.

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of individuals conducting similar research programs for high school students and teachers, and will serve to stimulate thought about the role such programs play in the contemporary science education reform movement.

High School Research Programs

Through my experience conducting CESIP, I have defined seven key issues that need to be addressed by individuals conducting a high school research program. These include: (i) recruiting targeted students; (ii) ensuring a quality research experience for the students; (iii) ensuring that the students have an in-depth understanding of the research process, including issues involved in sampling, data interpretation, and the relationship of science to wider societal issues; (iv) gaining support of university researchers for the program; (v) providing nonresearch science enrichment activities (related to teaching, ethics, and careers); (vi) ensuring that students feel comfortable and supported in the university setting; and (vii) building long-term sustainability of the program. Each of these will be discussed below.

Recruiting Targeted Students

We used targeted mailings and financial incentives to recruit students who may have had limited science enrichment opportunities. Through our college admissions office, we obtained lists of rural schools and schools with a high percentage of minority students in New York State. We then mailed recruitment brochures to science departments in these schools. In addition to applications from the targeted groups, we received applications from groups that would not be considered underrepresented minorities, e.g., immigrants from the former Soviet Union and southeast Asia. Like the applications from minority and rural students, these applications were considered favorably because we felt these students often had limited enrichment opportunities and would add diversity to the program. Although we did not obtain financial information on the students’ families, we did ask the parents’ profession and made an attempt to accept students whose parents’ employment indicated they had not attended college. Thus, the final group of interns was dominated by, but not limited to, students with limited enrichment opportunities. All interns received a $600 stipend and room and board during the program.

Quality Research Experience

It is challenging to strike a balance between providing a novice student researcher with needed guidance and allowing him or her the opportunity to define a question of interest and conduct a research project from start to finish. To protect against exploiting students through having them do mundane lab tasks, student research programs generally strive toward a goal of having each student conduct an independent research project. However, many high school students do not have the ability to define a researchable question within a 6-wk program. Additionally, unpaid mentors cannot be expected to spend the time away from their own research that would be required for them to guide a high school student conducting a project wholly of his or her own design. Students also benefit from being part of a research team, both in learning specific research skills and in developing an understanding of the cooperative nature of research.

Thus, we encouraged CESIP mentors to involve their students in their overall research project, as well as to define one part of that project that the student would have responsibility for in terms of collecting and analyzing data and writing the results. During the first few weeks of the program, the high school students usually helped the graduate students and other researchers with ongoing projects, and worked to identify their smaller individual projects. During the latter part of the program, the students collected and analyzed data on their own projects and developed their final presentations and papers. Thus, we defined the students’ research experience to include: (i) a period of becoming familiar with the overall lab or field project’s goals and research activities and helping other researchers with their projects; (ii) conducting a small, independent research project related to the overall project, in which our students collected, analyzed, and interpreted their own data; and (iii) presenting the results of their project in a slide presentation and research paper.

Using the above as a working definition for a student research experience, we identified mentors who were committed to providing this kind of experience to high school students. We found that making personal contacts is more successful than putting out broadcast requests for mentors. In speaking with prospective mentors, it was fairly easy to discern how enthusiastic they were about the program’s goals and to exclude those who were not concerned with the students’ overall educational experience. Many prospective mentors were familiar with high school student research programs and had an immediate understanding of the goals of such programs. (Some mentors had participated in similar research programs while in high school.) Others required lengthy conversations to determine whether they could offer the kind of experience we sought. The overwhelming majority of the mentors worked well with the students and helped the students to develop research skills and understanding.

Creating a quality research experience is a responsibility not only of the research mentor, but also of the student. During a discussion of research processes at the program orientation and during weekly meetings throughout the program (see Table 1), we tried to instill in the students the importance of taking personal responsibility for making their own research experience valuable, through becoming actively engaged in understanding all aspects of the activities in their lab. We encouraged the students to ask questions of their mentors about each aspect of the research. We emphasized that asking questions was not only important to enhance their own understanding, but also would be important to their gaining acceptance as full members of their lab group, i.e., asking questions was part of the culture of conducting research. We also pointed out that their interest would flatter their mentors—everyone, including scientists, appreciates it when people show an interest in their knowledge and work.

Understanding of Research Process

For students to develop an understanding of the overall research process, as well as of their specific research project,
it is essential to include activities in addition to conducting the actual research. Most mentors are engaged in guiding the students in research tasks and do not necessarily help them to gain an overall perspective on the research process. Additionally, mentors and students do not always realize the extent and limitations of student understanding of their individual research projects.

We conducted a number of activities to ensure that our participants had an understanding of the steps involved in conducting research in a university setting. Although the high school teachers were included in the joint activities, in most cases they had no prior research experience themselves, so they were learning along with the students. During the program orientation, the entire group participated in a 1-d, miniresearch project before starting their work in individual research labs. The miniresearch session focused on the impact of several potential pollution sources on stream water quality. Shortly before we conducted our session, the university had installed a pipeline suspended across the stream; this involved driving heavy vehicles across the stream bed and stripping the soil of vegetation on both sides of the stream (silt fences were installed). In addition, there was a pipe that conducted overflow from the parking lot adjacent to the nearby heating plant leading directly into the stream. The students and teachers were first trained in using simple chemical test kits to measure water quality and surveying aquatic invertebrates to evaluate biotic diversity. They then divided into groups of five and were asked to determine whether or not the disturbances along the stream had any impact on stream water quality. The students collected and analyzed their data without further input from the staff, although individuals knowledgeable about the chemical and biological monitoring protocols were available during the exercise to answer questions.

Following the exercise, the students and teachers discussed their results with the larger group of students, teachers, and staff. We then presented a model of the steps involved in conducting scientific research (Fig. 1) and held a discussion of how the students approached their miniresearch project relative to this model.

A number of interesting lessons developed out of this exercise and were pointed out to the students during the discussion. First, the students tended to jump right into taking water and invertebrate samples, without any discussion about where to sample, what tests to conduct, or how many samples to take. They assumed they should sample upstream and downstream of the two disturbances, but did not focus on identifying similar habitats for sampling. Only some of the groups took into account the fact that there were at least two potential disturbances or sources of pollution very different in nature, and how this might impact their sampling scheme. Thus, part of the discussion after the exercise focused on the importance of developing a sampling plan.

Second, the students almost uniformly assumed that the disturbance did have a negative effect on water quality, and this was an important factor in the way in which they interpreted their results. For example, 1 year, the difference between the biotic index scores was greater between groups than between upstream and downstream sites, yet the students assumed that the upstream–downstream differences were evidence of a disturbance effect regardless of the variability among sampling groups. Even after a discussion of researcher bias and meaningful differences, one of the teachers stated she refused to believe that the disturbance did not have a negative impact on the stream. Her convictions seemed to be based on her commitment to being an environmentalist, and unwillingness to adjust preconceived notions based on the data the group had collected. For the most part, however, the students and teachers were able to understand the insignificance of the differences they found above and below the disturbance.

We asked each participant to share with the group the most important thing he or she had learned through conducting the miniresearch project. About half of the responses related to subject matter (e.g., I learned to identify aquatic invertebrates) and half to research processes (e.g., I learned that I was biased in my interpretation of results).

In some years of the program, we conducted a discussion of the research process through asking each student to briefly describe past research experiences, and then analyz-

\begin{table}
\centering
\caption{Cornell Environmental Sciences Interns Program (example summer schedule).}
\begin{tabular}{|c|l|}
\hline
\textbf{Week 1} & \\
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Monday & 9:00–12:00 Group building exercise \\
1:00–2:00 & Lab and field safety \\
2:00–3:00 & Travel to Cornell Research Forest \\
3:00–6:00 & Recreation \\
\hline
Tuesday & 9:00–10:30 Program overview and expectations \\
10:30–5:00 & Miniresearch project—introduction, data collection and analysis \\
1:00–3:00 & Reading scientific literature \\
3:00–4:00 & Return to Cornell campus \\
\hline
Wednesday & 9:00–12:00 Miniresearch project—presentation and discussion of results, discussion of research model \\
1:00–3:00 & Reading scientific literature \\
3:00–4:00 & College admissions \\
\hline
Thursday & 8:00–12:00 TEAM challenge/ropes course \\
12:00–3:00 & Sightseeing in local park \\
3:00–5:00 & College admissions \\
\hline
Friday & 9:00–10:30 Careers: Identifying factors important in a job \\
10:30–11:30 & Library orientation \\
1:00–2:30 & Ethics seminar \\
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\end{tabular}
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ing in-depth one student's past research project using the research model (Fig. 1). We found that the 1-d miniresearch session was more successful than analyzing a past research project in engaging students in a discussion of the research process.

In the final year of the project, we added a group research project that extended over 4 wk of the 6-wk program. Journal writing assignments and discussions related to the group research project were used to encourage students to reflect on the nature of conducting research (e.g., the strengths and weaknesses of lab and field research in answering questions having to do with the environment, the importance of examining decisions that are made at each step of the research process). This group project, which focused on the effect of invasive worms on soil properties, was conducted in cooperation with an ecosystem scientist. Although not a specific goal of the project, the results turned out to have scientific merit, and are being incorporated by the scientist into a journal publication.

To ensure that the students developed an understanding of their individual research projects, as well as to reinforce their understanding of the overall research process developed through the activities discussed above, we held weekly small-group research check-ins during which the students applied different steps of the research model (Fig. 1) to their research. For example, during the first week we assigned the students to learn about Steps 1 to 4 (real world problem addressed by their research, background information, hypotheses), during the second week Steps 5 to 6 (methods), and so on. Each week they had to report to the group about what they had learned. If they were unable to address one of the steps of the research model, they were asked to question their mentors until they learned enough to report back to the group.

Finally, developing slide presentations and writing the final papers (a number of which were published in the Journal of Student Research—Arifovic, 1997; Dizhur, 1997; Kim, 1997; Schulman, 1997) provided an incentive for the students to interact with their mentors and to develop a more thorough understanding of their research. The program staff worked intensively with each student to develop the presentations, and to ensure that the students were able to explain their research to a mixed group of scientists and lay people. Each student presented his/her

![Fig. 1. A model for conducting research (adapted from Murphy, 1990).](image-url)
research at the final banquet, which was attended by about 100 family members, mentors, program staff, college administrators, and friends.

Support of Research Mentors

Providing benefits to scientists who participate in programs designed to engage students and teachers in research is essential to the success of such programs (Berkowitz, 1997). Although some high school research programs pay the participating mentors, we did not include financial incentives for researchers in our program. Through conversations with mentors, we have discovered a number of other motivations for scientists participating in such programs.

Personal Commitment to Promoting the Careers of Promising Young Scientists, Especially Those from Minority and Other Underserved Groups. For individuals who are committed to promoting the careers of young scientists, particularly minority scientists at a predominantly Caucasian university like Cornell, a high school or teacher research program provides one of the few opportunities to act on their convictions. Many scientists participated in similar research programs when they were in high school, or attribute their interest in science to a key mentor they had as a student, and thus feel they are paying back the help they received early on in their careers. It may also be important for them to know that they are part of a larger NSF program that helps many students and teachers. A personal commitment to helping young people with an interest in science was the most common reason for scientists participating in the program.

Providing Mentoring Experience for Graduate Students. Some professors participated in the program because they saw an opportunity for their graduate students to gain experience mentoring younger students. They felt this experience would put their graduate students at a competitive advantage when later looking for academic jobs in which they would be mentoring undergraduate and graduate students.

Contact with Students. Many professors and graduate students enjoyed having the bright, young students in their labs. Some research scientists, for example, those at a USDA lab and several private research institutes affiliated with the university, have relatively little contact with students. These individuals in particular enjoyed the opportunity to work with young people.

Interested in Learning from Minority Students and Students with Disabilities. One foreign-born scientist who had not had much association with African-American and other minority U.S. cultures was interested in learning about different cultural perspectives. Another scientist who worked with several high school students with disabilities, including a deaf student and a student in a wheelchair, felt that he could learn a lot personally from students who were dealing with these sorts of challenges.

Wanting to Help Out. Some scientists may have participated because helping youth was the right thing to do or because they knew the program director and staff and wanted to help them out. These scientists were generally less committed than scientists with other motivations to spend the time necessary to mentor the high school students.

Help in Accomplishing Their Research. In general, mentors felt the help they got in their research was equal to the amount of time they spent working with the students. In other words, there was usually not a net loss of time associated with including a student in their lab, but neither was there a gain in terms of help accomplishing their overall research agenda. In several labor-intensive field projects, the scientists did appreciate the help our students were able to offer. We were careful to try to exclude scientists whose motivation for participating in the program was added labor.

We provided only minimal rewards for the mentors outside of actually working with the students. We invited the mentors to our final luncheon banquet and student research presentations, gave them student-designed CESIP T-shirts, and wrote them thank you letters at the conclusion of the program.

It is important to consider not only the benefits that might accrue to scientists participating in a high school research program, but also how to reduce the costs of participation. Thus, we tried to eliminate any costs to the scientists other than mentoring. The program staff (i) took all responsibility for recruiting and accepting the students; (ii) were able to secure a large applicant pool that allowed us to choose outstanding students; (iii) took care of all living arrangements and social events; (iv) introduced the students to the steps involved in conducting research; (v) trained the students in how to develop research presentations, write research papers, and use the relevant computer software; and (vi) produced the final presentation slides in cooperation with the students. We did hold one meeting of the researchers before the start of the program each year, to ensure that the researchers understood the program goals and knew how to mentor high school students. We also discussed (individually with each mentor) the program goals and the research projects on which the students would be working.

Enrichment Activities

We conducted nonresearch enrichment activities with the entire group of interns (Table 1). These activities were designed to enhance the students’ understanding of philosophy and ethics of science and the environment, promote a sense of responsibility in conducting and teaching science, and expose the students to a wide range of careers in environmental sciences.

The weekly ethics seminar covered topics such as how philosophers think about ethics, applications of ethical theory to questions relevant to science research (e.g., What is a fact? How do we know something is true?), the importance of truth in research, and the application of ethical thinking to the environmental sciences (e.g., Is the life of a single human being or the continued existence of an endangered species more important?). The seminar ended with a discussion of the importance of our connectedness with others and the planet, and how we can, as individuals and scientists, live and work in an ethical manner.

To promote a sense of responsibility toward others, the students developed and conducted weekly environmental education lessons for a group of elementary-aged youth participating in an urban day camp. They conducted similar lessons with youth in their community during the school
year using activity packets they helped develop during the summer.

The CESIP career explorations component was designed to encourage active engagement of the students—both in thinking about what was important to them in a career and how to research careers. The students first engaged in an exercise to help them identify factors important to them in a career (e.g., degree of independence, salary, creativity). They then used these factors to develop a list of questions to ask each of the professionals who participated in our career explorations. Thus, the career segment was more like an interview in which students were actively questioning the professionals, rather than a series of lecture-style presentations. Because we realized during the course of the program that the students had little understanding of the difference between undergraduate and graduate degrees, and what sorts of opportunities were opened up by graduate degrees, we brought in professionals with varying levels of education.

**Supportive Environment for the Students**

For many of our students, coming to Cornell for 6 wk was the first time they had been away from their families. Through housing our students in dorms with 800 other high school students who attended Cornell University Summer College, we were able to provide a living environment that was safe and allowed our students opportunities to meet other high-ability students from around the world. Additionally, the Summer College provided the students with recreational, cultural, and social activities. In fact, in a 1992 survey of CESIP interns, living in the dormitories was rated as the most important aspect of the program (followed closely by the research experience; Krasny and Marchell, 1993). Being able to tap into an ongoing residential living program allowed us to focus our energies on the science and related activities.

**Program Sustainability**

Ensuring the long-term sustainability of a high school research program presents a major challenge. Conducting these programs requires a substantial time commitment on the part of the director during the school year when students must be recruited and selected, as well as during the summer research experience. Although the NSF funds enabled us to hire a full-time program coordinator and support staff during the summer, there was not sufficient money to keep a staff person during the academic year to cover the application process and to help students in their follow-up activities. In 1 yr, we obtained funding from USDA, which was more restrictive than that from NSF; the USDA funds were only for direct support of student expenses and did not allow hiring any staff. The combined administrative tasks were a major factor in the decision to discontinue the program.

Because high school research programs can serve as important vehicles for recruiting underrepresented minority and rural students, a number of college administrations seek support for and administer such programs. About one-third of CESIP students matriculated at Cornell the year following their research internship; had we worked more closely with admissions, CESIP could have been even more effective as a recruiting tool. Without CESIP, many of these students may not have had the confidence to apply to Cornell, and for some, the summer research experience probably provided a competitive advantage in the admission decision. Currently, the College of Agriculture and Life Sciences at Cornell is considering implementing a summer program for high school students. However, a program designed to recruit undergraduates will not necessarily have a strong emphasis on student research.

**Teacher Research Program**

Our teacher research program was designed to provide teachers with an authentic research experience and with ideas for conducting research with students in their classrooms. Although the national science education standards (AAAS, 1993; NRC, 1996) call for all students to carry out genuine science investigations, few high school science teachers themselves have had experience conducting research (Arora and Kean, 1992). Thus, providing teachers with a research experience is important in itself, especially when combined with activities designed to help them understand the nature of scientific research, such as those described above for the students. Additionally, we felt our program would have more impact on science education if the teachers learned research protocols that they could repeat in their classroom. Composting research, because it can be conducted without expensive equipment or hazardous chemicals, turned out to be ideal for adaptation to the high school level. For example, several teachers worked in a compost engineering lab and learned how to make small-scale compost bioreactors to model physical and chemical processes of decomposition. They were able to simplify and adapt these ideas to create small-scale reactors that their students could build and use for individual research projects (Trautmann and Krasny, 1998).

Balancing the research and pedagogical goals of the teacher program presented a constant challenge for us and the teachers. In spite of the frustration caused by conflicting demands, all of the teachers successfully conducted a research project and helped to develop materials that have been incorporated into a teacher manual for conducting composting research in high schools (Trautmann and Krasny, 1998).

If one’s goals are solely for teachers to develop research-based instructional materials, a teacher program in which teachers work in laboratories strictly to adapt research protocols for use in classroom settings may be preferable to a teacher research program. However, assuming teachers will only be able to guide students in research-based instruction consistent with the national science education standards if they have conducted research themselves, a need will still exist for teacher research programs.

**Looking to the Future**

Students participating in high school research programs report very positive impacts in terms of strengthening interest in science, gaining an awareness of a community of science professionals, and having a positive research experience (Krasny and Marchell, 1993; Sharp et al., 1994). In short, there is no doubt that such programs have a powerful impact on the participants.
However, because participants in these programs have already expressed an interest in and aptitude for science, the programs have not been proven to increase the number of students in the science, engineering, and math (SEM) pipeline. In fact, applicants who did not participate in a Young Scholars Program chose science-related college majors and planned to pursue science careers as frequently as those who participated (Sharp et al., 1994). It should be noted, however, that about one-third of applicants had already taken part in science research programs before applying (Sharp et al., 1994), and it is likely many of them participated in other student research programs the summer they were rejected from a Young Scholars Program. It is thus possible that the combined effect of the many science enrichment programs on encouraging students to pursue math and science careers was significant, and that discontinuing all such programs would have a negative impact on the SEM pipeline.

To impact a broader group of students than was possible through the Young Scholars Program, NSF has shifted its emphasis from student research to teacher research programs (J. Clark, NSF, 1998, personal communication). It appears that the increased emphasis on teacher research programs has the potential to impact a larger number of students, including those who are not initially interested in science. Many of the lessons learned from conducting student research programs, including how to involve university researchers and how to ensure a rigorous research experience, can be applied to teacher research programs.

Even teacher research programs will be limited in their impact, as only teachers who are able to spend 4 to 6 wk on a university campus during the summer will be able to participate. Thus, to provide an opportunity for every student to conduct original research (NRC, 1996), we will need to develop additional means of reaching students and teachers. One possibility would be to provide miniresearch workshops for teachers, in which they conduct a short research project followed by a discussion of how they conducted their research, as in the water quality miniresearch project described above. Teachers who have participated in longer-term research projects could help conduct these miniresearch workshops in cooperation with scientists. To extend the impact of such short-term training programs, these efforts could lead to Student–Scientist Partnerships, in which scientists and high school classrooms conduct joint research projects and share data and ideas over the Internet (Cohen, 1997; TERC, 1997). Such efforts may entail widespread rethinking about the way in which scientists conduct research, as well as about the way in which science is taught in the high school classroom.

ACKNOWLEDGMENTS

CESIP was supported by the National Science Foundation Young Scholars Program (grants 8855008, 9055128, 9255924, and 9452750), by the USDA Research Apprenticeship Program for Minority Students (grant 96-COOP-2-2762), and by in-kind support from the College of Agriculture and Life Sciences at Cornell University. The author acknowledges the following individuals for their hard work in support of CESIP and for review of the manuscript: Dawn Chavez, Julia Clark, Noel Gurwick, Alpa Khandar, Timothy Marchell, Nancy Trautmann, and two anonymous reviewers. Thanks also to the many high school students who worked hard to make their summer research experience productive, and the Cornell faculty, graduate students, and other researchers who provided guidance for the high school students during their time at Cornell.

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