Evaluation Report of NIH K-12 Program

Title: Pilot Evaluation of the NIH Curriculum Supplement

Date: 2000

Description:
This report evaluates one component within the NIH K-12 program, the NIH Curriculum Supplements. The NIH Curriculum Supplements are K-12 teacher's guides to two weeks' of lessons that explore the science behind current health topics. The modules are sent free of charge upon request to educators across the United States. Over 50,000 educators have one or more curriculum supplement.

This evaluation is a pilot study that examines student outcome data of teachers who use the NIH Curriculum Supplements and comparable teachers that do not. 17 pairs of high school science teachers participated in the study.

The pilot evaluation provided empirical and anecdotal evidence that the curriculum supplements:

(1) promote higher science achievement;
(2) reduce academic inequity;
(3) stimulate student interest in medical topics;
(4) deepen students' understanding of the importance of basic research to advances in medicine and health;
(5) foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health; and
(6) encourage students to take more responsibility for their own health.

PILOT EVALUATION OF

THE NIH SCIENCE CURRICULUM SUPPLEMENTS

September 2000

Prepared for the Office of Science Education, National Institutes of Health

by

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EXECUTIVE SUMMARY

Description of the NIH Science Curriculum Supplements.

The National Institutes of Health (NIH) curriculum supplements were developed at the request of former NIH Director Harold Varmus, M.D., as part of a multimillion-dollar initiative designed to support the goals of the National Science Education Standards. The curriculum supplements provide resources to help students (1) understand a set of basic scientific principles; (2) experience the process of inquiry and develop an enhanced understanding of the nature and methods of science; and (3) recognize the role of science in society and the relationship between basic science and personal and public health.

In addition to offering cutting-edge science content, the science curriculum supplements support Standards-based teacher practices in ways that traditional curricula do not. The science curriculum supplements offer specific guidelines to help biology teachers implement inquiry-based instructional reforms by providing activities that (1) engage student interest in science; (2) allow students to explore a topic in detail in order to develop their own understanding of observations and phenomena; (3) help students develop detailed sets of explanations for the concepts they have been exploring; (4) provide time for students to elaborate or extend their understanding of a topic by attacking a new set of questions and experiences; and (5) ask students to use their understanding to evaluate and solve real-world problems.

Evaluation Purpose.

The primary purpose of the pilot evaluation was to assess the immediate impact of the NIH science curriculum supplements on students and teachers. Program impact was measured by the extent to which the curriculum supplements met six goals, namely, to

1. promote higher science achievement;

2. reduce academic inequity;
3. stimulate student interest in medical topics;
4. deepen students' understanding of the importance of basic research to advances in medicine and health;
5. foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health; and
6. encourage students to take more responsibility for their own health.

Evaluation Design and Implementation.

Data collected in the pilot evaluation were obtained from a sample of 17 pairs of biology teachers and their students in 14 public and private schools in New York City. In order to ensure group comparability, teachers were randomly assigned to use the curriculum supplements or not. Random assignment reduced the possibility that teachers who used the curriculum supplements might be different from their comparison groups in ways that could affect program outcomes. The mixed method of data collection included standardized assessments, work samples, and informal feedback. For each matched pair of classes, data were collected at the same time.

The effects of the curriculum supplements were measured by (1) comparing science achievement of biology students whose teachers used the curriculum supplements with that of students whose teachers presented instruction in a more traditional manner; (2) rating the quality of students' written work to determine how well individual students mastered each curriculum supplement objective; and (3) obtaining informal feedback from teachers about the practicality of using the supplements and their satisfaction with the supplements for improving instruction.

A comprehensive statistical analysis, which ranged from simple descriptive statistics to complex multilevel modeling, was conducted to estimate the effects of the curriculum supplements on science achievement and academic equity. Samples of student work and teacher comments provided a contextual framework for interpretation of the statistical analysis and evidence of attainment of specific program goals.

Results: Effects of the Science Curriculum Supplements.

The pilot evaluation provided empirical and anecdotal evidence that the curriculum supplements (1) promote higher science achievement; (2) reduce academic inequity; (3) stimulate student interest in medical topics; (4) deepen students' understanding of the importance of basic research to advances in medicine and health; (5) foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health; and (6) encourage students to take more responsibility for their own health.

Science Achievement. On average, science achievement was 15% higher in classes where teachers used a curriculum supplement than in similar classes where teachers used a traditional approach. When classroom differences associated with student aptitude, race-ethnicity, and gender were controlled, science achievement was 9% higher in classes where teachers emphasized engagement, 6% higher in classes where teachers emphasized further exploration, 6% higher in classes where teachers emphasized having students generate explanations, 1% higher in classes where teachers provided opportunities for students to elaborate or extend concepts and skills through laboratory inquiry, and 17% higher in classes where teachers encouraged students to evaluate and solve health-related problems.

Science Equity. Science achievement was more equitable in classrooms where teachers used the curriculum supplements. Minority students whose teachers used a curriculum supplement scored 16% higher on the science achievement test than did minority students in traditional classes. Compared to minority students in traditional classrooms, minority students did 18% better in classes where teachers emphasized science engagement, 13% better in classes where teachers emphasized further exploration, 12% better in classes where teachers emphasized further explanation, 14% better in classes where teachers emphasized elaboration through laboratory inquiry, and 12% better in classes where teachers emphasized evaluation and problem-solving. There is some evidence that the science curriculum supplements can contribute to more equitable achievement among males and females. Among students of equal aptitude, science achievement was 14% higher in classes where teachers used a curriculum supplement and 21% higher in classes where teachers emphasized elaboration through laboratory inquiry. It may be that the curriculum supplements can have a significant impact in disadvantaged schools where resources are limited and teachers rely on free materials to update their curriculum and implement Standards-based reforms.

<u>Student Interest in Medical Topics</u>. Virtually every teacher who used a curriculum supplement reported that the activities, particularly laboratory activities and games, stimulated student interest regardless of the level of their students. There is some evidence that greater student interest in medical topics motivated students to learn more science, even when the work was hard for them. There is some empirical evidence and much anecdotal evidence to suggest that interested students were more likely to do better on tests of science achievement and were more likely to recognize how science research was connected to their lives.

<u>Students Understanding of the Importance of Basic Research</u>. Each of the curriculum supplements contain activities that helped deepen students' understanding of the importance of basic research to advances in medicine and health. In particular, students demonstrated greater understanding of (1) how the basic biology of cancer can help us make sense of the many observations people have made about risk factors related to cancer; (2) the contribution that

epidemiology has made to our understanding of cancer and the emergence and re-emergence of infectious diseases; (3) different ways that basic research can lead to advances in medicine and health that offer a variety of strategies for alleviating suffering due to infectious diseases; (4) how advances in science and technology can be used help detect or diagnose disease; (5) contributions that scientists studying human genetic variation at the molecular level are making to modern medicine; (6) how research in genetics across the last century has contributed to clinical medicine and changed how physicians diagnose and treat human diseases; (7) some of the ways scientists use molecular information to improve disease treatment; and (8) how understanding the molecular structure of a disease-related gene can help scientists develop new strategies for treating the disease.

Student Analysis of the Direct and Indirect Effects of Scientific Discoveries. Teachers who used the supplements felt very strongly that in addition to being interesting, the activities in the curriculum supplements helped students apply creative and critical thinking skills to analyze the direct and indirect effects of scientific discoveries on their individual lives and on public health. Student work samples provide further evidence of attainment of this goal.

Student Responsibility for Their Health. The curriculum supplement activities encouraged students to take more responsibility for their own health. Students recognized relationships between their behaviors and health risks and reported that they would use this knowledge to choose healthier, more active lifestyles and to take control of their health. Students were able to explain how behavioral choices affect not only an individual's risk of developing a disease but also their chance of survival if they do develop it. Some activities also helped students take more responsibility for public health by considering the impact of personal decisions and community actions on the emergence or re-emergence of infectious diseases.

Unanticipated Findings. About 40% of the teachers who were randomly assigned to teach the curriculum supplement units taught only 1 or 2 activities. Three reasons teachers gave for not using the curriculum supplement were (1) the activities did not cover the objectives tested on state assessments; (2) the activities took too long to teach or took too much time away from other things they needed to cover; and (3) the reading and language were too sophisticated for their students.

Discussion.

Results of this pilot evaluation document the potential of the curriculum supplements for helping students (1) understand a set of basic scientific principles; (2) experience the process of inquiry and develop an enhanced understanding of the nature and methods of science; and (3) recognize the role of science in society and the relationship between basic science and personal and public health. Findings support NIH decisions to continue to commit funds to develop nine additional curriculum supplements scheduled for national distribution beginning in 2001 and can be used to (1) guide future curriculum supplement development, particularly in terms of refining estimates of the amount of time needed to teach the curriculum supplement activities; (2) guide future teacher training efforts designed to promote greater implementation of the curriculum supplements as vehicles for informing and changing teacher practice and supporting science education reforms; (3) strengthen designs of future curriculum supplement evaluations planned for other geographic regions of the United States; and (4) inform discussions by the broader scientific and educational research community about national science education policy.

PILOT EVALUATION OF
THE NIH SCIENCE CURRICULUM SUPPLEMENTS

Science Education at the National Institutes of Health.

The central mission of the National Institutes of Health (NIH)—the world's top medical research center—is improvement of personal and public health. The NIH works toward that goal by conducting research in its own laboratories and by supporting the research of nonfederal scientists throughout the country and abroad. The NIH also has a long history of committing human and fiscal resources to support national science education goals. The science curriculum supplements were developed at the request of former NIH Director Harold Varmus, M.D., as part of a multimillion-dollar initiative designed to support the goals of the National Science Education Standards.

Each of the NIH curriculum supplements is designed to help students accomplish three major goals associated with science literacy, namely, (1) to understand a set of basic scientific principles; (2) to experience the process of inquiry and develop an enhanced understanding of the nature and methods of science; and (3) to recognize the role of science in society and the relationship between basic science and personal and public health. The NIH science curriculum supplements accomplish these goals by bringing into science classrooms up-to-date information for teachers and students about the effects and significance of exciting medical discoveries being made at the NIH.

In addition to meeting curricular demands, the supplements fill a pedagogical need for an instructional bridge between education policy and classroom implementation of reform. Although the National Science Education Standards argue that learning is most successful when teachers provide students with active, collaborative, and inquiry-based learning experiences, most curricula do not provide a foundation on which the teachers can build such an instructional framework. The NIH curriculum supplements offer specific guidelines to help biology teachers implement inquiry-based instructional reforms by providing activities that (1) engage student interest in science; (2) allow students to explore a topic in detail in order to develop their own understanding of observations and phenomena; (3) help students develop detailed sets of explanations for the concepts they have been exploring; (4) provide time for students to elaborate or extend their understanding of a topic by attacking a new set of questions and experiences; and (5) ask students to use their understanding to evaluate and solve real-world problems. This *5E* (engage, explore, explain, elaborate, evaluate) approach forms the pedagogical underpinnings of the curriculum supplements and supports Standards-based teacher practices in ways that traditional curricula do not.

Description of the NIH Science Curriculum Supplements.

The first three supplements in the series, designed for use in senior high school science classrooms, are (1) Emerging and Re-emerging Infectious Diseases (with expertise from the National Institute of Allergy and Infectious Diseases); (2) Cell Biology and Cancer (with expertise from the National Cancer Institute); and (3) Human Genetic Variation (with expertise from the National Human Genome Research Institute). Each supplement contains five activities, printed materials, and a CD-ROM that contains scenarios, simulations, animations, and videos.

Emerging and Re-emerging Infectious Diseases consists of five activities that move students from an introduction to emerging and re-emerging infectious diseases (*Deadly Disease Among U*s), to an investigation of some of the causes for the emergence and re-emergence of infectious diseases (*Disease Detective*s, *Superbugs: An Evolving Concer*n, and *Protecting the*

Herd), to a discussion of how people make decisions about allocating funds to combat infectious diseases (*Making Hard Decision*s).

Cell Biology and Cancer consists of five activities that move students from an introduction to cancer (*The Faces of Cance*r), to an investigation of its biological basis (*Cancer and the Cell Cycle* and *Cancer as a Multistep Proces*s), to a discussion of how people evaluate claims about cancer (*Evaluating Claims About Cance*r), to a consideration of how under-standing cancer can help people make decisions about issues related to personal and public health (*Acting on Information About Cance*r).

Human Genetic Variation consists of five activities that move students from an introduction to human genetic variation (*Alike, But Not the Sam*e), to an investigation of its biological significance (*The Meaning of Genetic Variatio*n), to a discussion of some of the practical implications of human genetic variation for the treatment of disease (*Molecular Medicine Comes of Age* and *Are You Susceptible?*) and, finally, to a consideration of how understanding human genetic variation can affect the decisions we make about our own health (*Making Decisions in the Face of Uncertainty*).

Evaluation Purpose.

The curriculum supplements are expected to promote higher and more equitable science achievement, better understanding public health issues, enhanced knowledge of basic scientific principles, greater ability to use and interpret scientific data, and more sophisticated appreciation of the role of science in society and the relationship between basic science and personal and public health. The primary purpose of the pilot evaluation was to assess the impact of the curriculum supplements by answering 6 questions, namely:

1. Do the curriculum supplements promote higher science achievement?

2. Do the curriculum supplements reduce academic inequity?
3. Do the curriculum supplements stimulate student interest in medical topics?
4. Do the curriculum supplements deepen students' understanding of the importance of basic research to advances in medicine and health?
5. Do the curriculum supplements foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health?
6. Do the curriculum supplements encourage students to take more responsibility for their own health?

This report answers these 6 questions and presents some unexpected findings that may be used to guide development of future curriculum supplements scheduled for national distribution in 2001 and beyond and to inform decisions about the kind of teacher training required to promote use of existing curriculum supplements.

Evaluation Sample.

The results of this pilot evaluation are based on data obtained from a sample of 17 pairs of biology teachers and their students (approximately 900 students) in 14 public and private schools in New York City[1]. Each pair of teachers selected one teaching unit (*e.g.*, human genetics) on the basis of what they were scheduled to teach in Spring 2000, the semester this pilot evaluation was conducted. One teacher in each pair was randomly assigned[2] to use the curriculum supplement and the other was asked to teach the same or related content in his or her traditional way. Of the 17 teachers assigned to teach the supplements, 12 chose <u>Human Genetic Variation</u>, 3 chose <u>Cell Cycle and Cancer</u>, and 2 chose <u>Emerging and Re-emerging Infectious</u>

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[1] NIH acknowledges the contributions of key personnel at Columbia University who worked with the NIH Office of Science Education (OSE) to facilitate sample identification and data collection.

[2] Random assignment was used to control for outcomes that might be due to some teachers being better than others.

Diseases. In two schools where more than one pair of teachers participated, each pair selected different units.

Instrumentation.

The mixed method of data collection used standardized assessments, work samples, and informal feedback from teachers to gather quantitative and qualitative information about the impact of the curriculum supplements. For each matched pair of classes, data were collected at the same time.

Standardized Assessments. Two standardized assessments were administered to all students who participated in the pilot evaluation. The first, a diagnostic assessment given at the beginning of the unit, contained 42 items that measured students' demographic characteristics (gender and racial-ethnic status), science aptitude or general ability (25 items), attitudes about science (7 items), and instructional experiences (8 items). These items were used to control for variability in outcomes that might be explained by some students being smarter, more motivated, or having better teachers than others. The second assessment, given after the unit was taught, evaluated student satisfaction with the unit (5 items) and tested science achievement (30 items). The science achievement test was the dependent variable in the statistical analysis.

Work Samples. Work samples were collected from students whose teachers used a curriculum supplement. Each curriculum supplement contains a set of master worksheets that teachers can copy and distribute to students. In the pilot evaluation, worksheets for each curriculum supplement were copied and assembled into student workbooks. The evaluator was instructed to distribute workbooks to classes when teachers began teaching the curriculum supplement and to collect workbooks when the unit was finished. The workbooks provided written records of students' responses to supplement-specific performance assessment questions, tasks, and issues. Because student workbooks were coded with the same identification numbers as were used on standardized assessments, data obtained from them could be matched to individual records that also included information about student gender, racial-ethnic status, aptitude, science achievement, attitudes about science, course satisfaction, and instructional experiences. Student workbook samples were used to evaluate student interest in medical topics and understanding of key public health issues. In addition, classroom sets of workbooks provided an indication of how many activities in each unit were actually taught and how completely each activity was implemented.

Informal Teacher Feedback. Feedback from teachers about their reactions to and experiences using the curriculum supplements was collected through email correspondence over the Internet, telephone conversations, and on the two occasions that the evaluator visited each classroom to administer standardized assessments.

Data Analysis.

The effects of the curriculum supplements were measured by (1) comparing science achievement of biology students whose teachers used the curriculum supplements with that of students whose teachers presented instruction in a more traditional manner; (2) rating the quality of students' written work to determine how well individual students mastered each curriculum supplement objective; and (3) obtaining informal feedback from teachers about the practicality of using the supplements and their satisfaction with the supplements for improving instruction.

Statistical Analysis. Estimates of the effects of the curriculum supplements on science achievement and academic equity were obtained by using a widely accepted multilevel statistical technique, hierarchical linear modeling (HLM). HLM provided a measure of program excellence by estimating the effects of the curriculum supplements on mean science achievement of each class. HLM estimated also whether gaps in science achievement of students of different abilities, of males and females (gender gaps), or of students of different racial-ethnic status (minority gaps) were smaller in classes where teachers used the curriculum supplements. A technical description of HLM and its applications for program evaluation is available in Bryk and Raudenbush (1992[3]).

In general, results of statistical tests are considered significant if values of p are less than .05. One of the limitations of this interpretation is that the calculation of the value of p for a test statistic (*e.g.*, t-test) depends in part on sample size and variability. Analysis of a very large sample may produce a statistically significant result (*i.e.*, $p < .05$) that has limited practical value. Conversely, statistical tests conducted on small, highly variable samples, such as those used in this evaluation, can produce p-values that are not statistically significant even when the practical effects of a treatment are large. For this reason, results of statistical analyses evaluating the impact of using the curriculum supplements were summarized by effect size (ES) estimates and percentage differences in addition to p values.

ES estimates are standardized measures of the significance of statistical tests. The standardized measures allow comparison of outcomes with different metrics and yield results that are less sensitive to differences in sample size and variability. In educational research, effect size values of .10, .30, and .50 are interpreted as small, medium, or large, respectively (Cohen, 1988[4]). Another way to interpret p-values is in terms of percentage differences (Rosenthal & Rubin, 1982[5]). Values of 5%, 15%, and 25% correspond to small, medium, and large effects. In

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[3] Bryk, A. S. & Raudenbush, S. W. (1992). Hierarchical linear models: Applications and data analysis methods. Newbury Park, CA: Sage Publications.
[4] Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Erlbaum.
[5] Rosenthal, R. , & Rubin, D. B. (1982). A simple general purpose display of magnitude of experimental effect. Journal of Educational Psychology, 74, 166–169.

order to facilitate reader interpretation of the data, the main section of this evaluation describes outcomes in terms of percentage differences. Annotated results of statistical analyses, including a comparison of the *p*-values, effect size estimates, and percentage differences obtained from each HLM analysis, are provided in Appendix A.

Anecdotal Evidence. Each of the students in classes where the science curriculum supplements were taught received a workbook consisting of all of the worksheets for that unit. Students wrote responses to supplement-specific performance assessment questions, tasks, and issues. This report presents unedited student quotations from those workbooks. Errors in grammar, spelling, and language usage were retained to give the reader a better sense of the student's voice and the classroom contexts in which learning occurred. Teacher comments presented in this report are mainly extracted from email correspondence conducted over the course of the pilot evaluation.

Answers to 6 Evaluation Questions: Effects of Using the Curriculum Supplements.

1. **Do the curriculum supplements promote higher science achievement?**

In classes where students completed at least 3 of the supplement activities[6] average science achievement was approximately 15% higher than in classes where teachers used a traditional approach. The effects of particular teacher practices on science achievement further supported expectations that the NIH curriculum supplements would promote science reform goals. On average, science achievement was 9% higher in classes where teachers emphasized engagement, 6% higher in classes where teachers emphasized further exploration, 6% higher in classes where teachers emphasized having students generate explanations, 1% higher in classes where teachers provided opportunities for students to elaborate or extend concepts and skills

[6] The NIH defined curriculum supplement implementation as teaching at least 3 of the 5 activities. Only 10 of the 17 science teachers randomly assigned to use a curriculum supplement (60%) satisfied this criterion.

through laboratory inquiry[7], and 17% higher in classes where teachers encouraged students to evaluate and solve health-related problems. These outcomes demonstrate an impact of the curriculum supplements on achievement over and above any differences that could be explained by students' characteristics or school quality.

The curriculum supplements may indirectly influence science achievement throughout the year by providing concrete examples of how teachers can incorporate student-centered strategies such as cooperative learning and investigation of real-world problems into their existing curricula. Teachers commented that one reason the activities took so long to teach was that their students were used to more traditional, teacher-centered approaches. One said, "The NIH units provided me with a different outlook on how inquiry learning can be implemented into genetics." Informal classroom observations of students and teachers suggest that the supplements can encourage teachers to adopt inquiry-based instructional practices that are associated with higher science achievement.

The curriculum supplements may foster higher achievement on state assessments as well, particularly in schools were teachers have few other resources. One teacher from a disadvantaged school in Brooklyn reported the following update via email after the school year had ended. "I have good news. The students did well on the Regents exam. 56% passed in comparison to 5% and 10% in other sections of the same level students." Other teachers also reported that <u>Human Genetic Variation</u> prepared students for the genetics section of the *Regents* exam by encouraging them to examine relationships between some genetic variations and particular phenotypes and by helping them understand the molecular basis of disease.

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[7] Secondary analysis conducted by OSE on a national sample of biology students suggested that greater emphasis on laboratory inquiry would be associated with a 15% increase in achievement. Future OSE evaluations of the effects of the curriculum supplements on achievement of students in New York and across the country may help to explain this observed discrepancy.

2. Do the curriculum supplements reduce academic inequity?

The science curriculum supplements were associated with more equitable achievement among students of different racial-ethnic status. Preliminary examination of student performance revealed that, among females or males of equal ability, average science achievement of minority students was 11% lower than that of majority students. HLM analysis revealed that this difference varied significantly depending on curriculum and instruction. Minority students whose teachers taught at least 3 curriculum supplement activities scored 16% higher on the science achievement test than did minority students in traditional classes.

Examination of associations of each of 5 elements of the *5E* model with science achievement provided further support for claims that the curriculum supplements can promote academic equity. Compared to minority students in traditional classrooms, minority students did 18% better in classes where teachers emphasized science engagement, 13% better in classes where teachers emphasized further exploration, 12% better in classes where teachers emphasized further explanation, 14% better in classes where teachers emphasized elaboration through laboratory inquiry, and 12% better in classes where teachers emphasized evaluation and problem-solving. These differences were consistent for all minority students, regardless of gender or ability. These findings provide evidence that, aside from raising achievement of all students, the curriculum supplements can help narrow the gap in achievement among majority and minority students.

There is some evidence that the science curriculum supplements can contribute to more equitable achievement among males and females. Overall, average science achievement of males was 6% lower than that of females regardless of racial-ethnic status or ability. This gap was 10% smaller in classes where teachers taught at least three curriculum supplement activities. In addition, there were small reductions in gender gaps in achievement (from 3% to 7%) in classes where teachers emphasized science engagement, further exploration, and evaluation. This result, though small, points to the potential of Standards-based curriculum and instruction for narrowing gender gaps in achievement.

As expected, students with higher aptitude scores also had higher science achievement scores. What was significant for this evaluation were differences in science achievement observed among students whose aptitudes were the same. Among students of equal aptitude, science achievement was 14% higher in classes where teachers taught at least 3 of the curriculum supplement activities and 21% higher in classes where teachers emphasized elaboration through laboratory inquiry. This pattern was consistent for students of all ability levels regardless of gender or minority status. These findings suggest that the curriculum supplements may help to reduce academic inequities associated with poor school quality and social disadvantage.

Teachers who taught in disadvantaged high schools were more likely to fully implement the supplements even though their students were reading at elementary levels, had low prior science achievement, and had virtually no experience working in groups, let alone in laboratory settings. Examination of achievement data and students' work samples revealed that even though disadvantaged students wrote less sophisticated responses to the questions associated with each activity than did more advantaged students, they were able to identify and analyze medical issues and evaluate and solve health-related problems. Dissemination of free NIH science curriculum supplements in disadvantaged schools will increase accessibility to Standards-based science education opportunities in classes where resources historically are most limited and where teachers rely on free materials to update their curriculum and implement instructional reforms. Greater accessibility to educational opportunities may improve academic equity.

3. Do the curriculum supplements stimulate student interest in medical topics?

Virtually every teacher who used a curriculum supplement remarked about how well the activities, particularly laboratory activities and games, stimulated student interest in medical topics regardless of the level of their students. A teacher from an exclusive private school in the Bronx wrote, “Overall, the genetics unit was excellent. The students enjoyed doing these worksheets and they indicated that they learned a lot from them.” Another teacher from a disadvantaged vocational school in Brooklyn echoed that evaluation, writing, “All students were engaged in the learning process.” Results support theoretical expectations that increased student interest in medical topics is associated indirectly with higher science achievement.

During the early planning stages for development of the curriculum supplements science teachers requested specifically that one module focus on ways to make the biology unit on cell cycle more relevant for their students. In response to that request, Cell Biology and Cancer was produced with an aim toward helping students better connect science concepts to their own experiences. Analysis of responses of approximately 150 students in 6 classes suggested that NIH met this goal. In three classes where teachers used this curriculum supplement as part of the cell cycle unit, students’ ratings of how well the information was connected to their lives were 96% higher than the ratings of similar students in three comparison classes.

The teachers expressed pleasant surprise at how well even simple introductory activities sparked student enthusiasm for the unit. One teacher wrote, “*Alike, But Not the Sam*e...turned into an excellent lesson.” Another teacher explained, “The students enjoyed *Alike, But Not the Sam*e because they enjoyed examining if they were dominant or recessive for particular traits. As a result of this lesson the class began discussing pedigree charts and one student made a pedigree chart tracing her family’s traits. The poster-size chart is currently on display in our classroom.”

In this class, interest in medical topics led to greater student engagement and more in-depth study, two outcomes that are statistically significant predictors of higher science achievement.

One compelling example of the relationship between student interest in medical topics and achievement came from a class of low-achieving students at a disadvantaged high school in Queens. The teacher used approximately $250 of his personal funds to purchase materials for *Superbugs: An Evolving Concer*n. His explanation for this unusually high implementation cost was, "School laboratory equipment and facilities were insufficient to carry out lessons effectively." Even the most basic laboratory equipment and science supplies (*e.g.*, petri dishes, nutrient agar) were unavailable at his school. He spent over a month teaching five activities to students who heretofore had almost no experience working in groups, reading complex material, practicing laboratory techniques, or writing extended reports. He reported that the activities increased interest in biomedical topics even though "students had difficulty interpreting the readings." On the science achievement test administered at the end of the unit, his students did 47% better than students in a comparison class at the same school. Student interest in medical topics was a catalyst for instructional changes that led to higher science achievement.

4. Do the curriculum supplements deepen students' understanding of the importance of basic research to advances in medicine and health?

Activities in each of the curriculum supplements helped deepen students' understanding of the importance of basic research to advances in medicine and health.

By examining the events and processes that occur as both normal and abnormal cells grow and divide, students gained a deeper understanding of the processes involved in the development of cancer. Prior to completing *Cancer and the Cell Cycle*, students had many misconceptions about cancer. For example, a number of students wrote that they were surprised to learn from the introductory activity, *Faces of Cancer*, that "cancer cannot be spread by sex." Others wrote that they were surprised that "cancer occurs in so many different parts of the body." After completing *Cancer and the Cell Cycle*, students were able to explain the biological bases of the roles that chemical poisons, family history, radiation exposure, and ultraviolet light play in causing cancer, and to make sense of the many observations people have made about risk factors related to cancer.

In *Cancer as a Multistep Process* students analyzed the frequencies with which cancer occurs in large populations. They calculated the likelihood of developing cancer at different ages and observed that cancer incidence increases with age. One teacher who used this supplement commented, "The graphing in Masters 3.3 and 3.4 were excellent exercises for students." Students concluded from the graphical data that colon cancer results from the accumulation of genetic damage to cells across time. As one wrote, "The risk of a person developing colon cancer increases as little mutations accumulate." Many students wrote that they were surprised at the implications of this finding. One concluded, "What you do when you're young doesn't immediately affect you." *Cancer as a Multistep Process* helped students appreciate the contribution that epidemiology has made to our understanding of cancer.

Making Hard Decisions, the culminating activity in Emerging and Re-emerging Infectious Diseases, helped students understand and apply relevant biological principles involved in making difficult decisions about which research priorities to fund. For example, one wrote that research to develop new drug therapies against *Staphylococcus aureus* is "very serious because the disease becomes more and more resistant to antibiotics." A student struck by the contagiousness of measles in some populations drew on principles of herd immunity learned in *Protecting the Herd* to support a proposal for production and distribution of a measles vaccine.

Another student wrote that she "considered how the death rates [for AIDS] came to increase over the years." Students were more aware of different ways that basic research can lead to advances in medicine and health and alleviate suffering due to infectious diseases.

In deciding which research direction was most important, students considered the magnitude of the problem. One consideration was the number of people affected, or in their words, "how many people were succetable to the disease," and "how many people is being killed by this disease." Another factor that influenced students' support for research in a particular area was their perception of the seriousness of the consequences of having the disease. One student gave the highest rating to a proposal to produce and distribute drugs to HIV-positive individuals. He justified his decision by writing, "I think the magnitude of this situation is bigger than any. If there is any type of advantage in the help for AIDS then we should give money to that cause. Many people are affected and it can be anyone. A family member, a friend, a teacher, and anyone you look up to. Of all the consequences dying a slow death is the worst."

The emotional consequences associated with AIDS were a decisive factor for other students as well. One wrote, "So much people were dieing from aids and they don't have no cure for this diseases. So that makes me feel so sorry for these people who have aids. The other diseases dosen't makes me feel emotional like aids do." Another was touched to learn people were dying at a rate of "not hundreds a year but millions a year" and wanted "to help people who are dying of sadness, seeing there friends and family dying from this ugly virus."

Students also considered the likely effectiveness of the treatment plan. One student gave the AIDS proposal a lower rating because of her intuitive appreciation of a high cost to benefit ratio. She wrote "Unlike measles and VRSA you can't really get rid of AIDS. The medicine they have just helps you live a little longer and in order to get the medicine you need a lot of money."

Another student pointed out that basic research is not a panacea and commented on the need for individuals to take more personal responsibility to prevent disease transmission. He wrote, “The treatment for AIDS is not a cure so it is going to be in some ways helpful and not. To prevent this disease all people should use methods of protection in having sex, using needles, drugs and other ways of contracting AIDS through sexual ways.” Another added “it don’t make any cents how people are going around having unprotected sex and sharing needles.”

The readings associated with *Making Hard Decision*s generated student support for further biomedical research to find cures for diseases and to lower the costs of treatments. A number of students were very concerned to learn that so many affected individuals were children. One wrote, “I considered the 510,000 kids under 15 that dies of [AIDS] and realized that these were kids my age. This also gave me an eagerness to research AIDS.” Another wrote, “I considered the fact that a lot of the treatment and medication the patiens get is expensive. And with the money that we are giving them they might be able to do more research or lower the costs for some less fortunate.”

One way the supplements deepened students’ understanding of the importance of basic research to advances in medicine and health was by providing specific examples of how advances in science and technology can be used help detect or diagnose disease. *The Meaning of Genetic Variation* required students to conduct simulations of real-life studies of genetic variation at the molecular level. Examinations of DNA sequences and analyses of a DNA electrophoresis gel allowed students to evaluate the differences in the DNA of people whose cells make sickle hemoglobin as compared with people whose cells make normal hemoglobin. Students concluded that, “at the molecular level humans are more alike than they are different.

99.9% of the bases in all humans are the same. Even a small percentage difference can represent a very large actual number of differences in the human genome."

Molecular Medicine Comes of Age increased student awareness of how research in genetics across the last century has contributed to clinical medicine and changed how physicians diagnose and treat human diseases. Through investigation of individuals' variable responses to asthma drug X, students recognized that "people with different genotypes respond differently to drug X." One wrote, "We have concluded that there is a varying gene that changes a person's tendency to contract asthma. We have learned that having pets has little effect and sex has no affect. Those that have the arginine [genotype] will be more receptive to Drug X." Another student wrote, "We need to have a new drug for the people who do not get much relief."

Most students were able to point out that solving this problem raised a number of new issues including the logistics and expense involved in genetic testing, the need to educate physicians, and the need to develop alternative therapies for persons with different genotypes. One wrote, "A new problem is the difficulty and expense of testing all asthma patients." Another asked, "[If] patients do get tested who will pay for this? Will health care pay?" Another student added, "Doctors have to be educated enough to explain what's going on with the patients." A fourth student concluded, "You cannot change the percentage of a certain protein in the body, so the company needs to make a new drug for the people [with genotype] ApoE4."

An alternative investigation in *Molecular Medicine Comes of Age* asked students to investigate development of treatment strategies targeted at a disease's biochemical mechanism. Students concluded, "[Drug Y] treated the symptoms, not the cause." Students proposed research, such as "using small fragments of a protein normally found in brain cells to create working chloride channels in CF cells that lack such channels." Students were committed to further study. One wrote his team "will never stop researching and trying to make the disease CF not feared as much. New problems always arise and we are researching and experimenting to try to stop those problems before they arise." Other students were concerned with practical limitations such as the cost of drug development. One worried, "If [our research] doesn't work, [Firm B] will go bankrupt." Another concluded, "We need a drug that we can sell, works, and doesn't cost too much to produce." Overall, students who completed *The Meaning of Genetic Variatio*n and *Molecular Medicine Comes of Age* were able to explain how understanding the molecular structure of a disease-related gene can help scientists develop new strategies for treating the disease.

5. Do the curriculum supplements foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health?

Teachers who used the supplements felt very strongly that in addition to being interesting, the activities in the curriculum supplements helped students apply creative and critical thinking skills to analyze the direct and indirect effects of scientific discoveries on their individual lives and on public health. A teacher who taught Emerging and Re-emerging Infectious Diseases explained that students were more likely to think critically because "students enjoyed trying to figure out the different situations presented to them." The activities offer opportunities to explore the impact of science research in ways that are uncommon in traditional textbook-based curricula.

*Evaluating Claims About Cance*r provided an opportunity for students to discover how scientific evidence can be used to help individuals and society evaluate health risks. Students designed, conducted, and analyzed results of controlled experiments that evaluated media claims about cancer. In so doing, students applied the same systematic and rigorous criteria used by scientists, namely, evaluation of the source, certainty, and reasonableness of the supporting information. One teacher reported that students particularly enjoyed *Evaluating Claims About Cance*r and that she stayed after school to help enthusiastic students finish their investigations. It is noteworthy that students in her class did 65% better on the science achievement test than students in a comparison class at the same school.

One teacher commented on the "teachable moment" offered to her low-achieving students by the culminating activity in the unit on <u>Human Genetic Variation</u>. She wrote, "*Making Decisions in the Face of Uncertainty* was my personal favorite [activity] and I think it was the most beneficial for the class as a whole. To begin with, the students learned new vocabulary such as mastectomy and most students knew at least one person that had or has cancer. This lesson led to a discussion about the human genome project and the implications that this information will have on society. The students were willing to talk about their own experiences with cancer and I was surprised at how maturely the students discussed this sensitive topic. It also raised many questions about the disease which the students may not have asked without the supplement use." This comment is a dramatic example of how the curriculum supplements can enhance or support treatment of biology concepts and the relationship between basic science and personal health.

Students applied information obtained from *Superbugs: An Evolving Concer*n to evaluate problems associated with imprudent use of antibiotics. In response to a query about how to respond to patients' insistence that doctors prescribe antibiotics before they know the cause of an illness, a student wrote, "… antibiotics would otherwise be useless against a virus yet will affect bacteria." A classmate added, "A flu or 24 hr. virus is temperoy and don't need medication." In discussing using antibiotics in livestock feed, one student concluded, "Overuse of antibiotics in some cases leads to immunity of diseases for it." Regarding using antibacterial drugs in products for healthy people (*e.g.*, hand soaps, toys) one wrote, "Not all toys should have antibacterial drugs in their products [because it makes] the resistant bacteria reproduce." A classmate added, "It will kill the germs that the humans might have. There are more resent bacteria that will survive. Where helping the bacteria that is not immune grow." One student wrote in her final evaluation, "It helped me a lot because through the biology of infectious diseases I learned about antibiotics and diseases being resistant." On average, students recognized that over-prescribing medications and over-use of antibiotics leads to drug resistance[8].

6. Do the curriculum supplements encourage students to take more responsibility for their own health?

Evidence from teacher reports and student work samples suggests that all the curriculum supplements include activities that encourage students to take more responsibility for their own health.

Are You Susceptible? focused on the likelihood that genetic testing for common multifactorial diseases such as heart disease would increase in the future and invited students to consider the implications of having this knowledge. Students recognized that because all diseases, except perhaps trauma, have both a genetic and environmental component, certain behaviors can increase or reduce a person's risk of experiencing certain medical outcomes.

One teacher sent an email saying, "*Are You Susceptible?* was the class' favorite out of the five activities. The students enjoyed rolling the dice and I was surprised at how seriously they took the game. Throughout the period the students were anticipating whether or not they would end up having the fatal heart attack. One could hear the sighs of relief when their totals added up

[8] While students understood that overuse of antibiotic treatments exacerbates drug resistance, many wrote that humans, rather than bacteria, were immune to antibiotics. Further clarification may be necessary to correct this misconception among students, and possibly, among teachers.

to less than the doomed amount of points. Their enthusiasm led us to a class discussion regarding genetic and environmental health risks." *Are You Susceptible?* clearly helped students recognize the relationship between their behaviors and health risks.

In their written responses, students in different classes consistently mentioned using knowledge about their genetic risks for disease to choose healthier, more active lifestyles and to take control of their health. As one student wrote, "You can't change genes [but] I could change my behaviors to decrease my chances of a heart attack." Another student specified, "I would exercise, eat healthy foods, and make sure I never start smoking. Physicians cannot help every effect of a disease alone. Patients have to take steps towards prevention." Echoing recognition of the shift in responsibility for health care from physicians to individuals, a student wrote, "Individuals will garner more responsibility because they will have control over their environmental factors. The physicians will then not be as needed." Another added, "If people would not carry on with risk behaviors then that will cut down on the work for physicians." Students understood that the ability to detect genes associated with common diseases increases the prospects for prevention.

The Faces of Cancer generated many comments from students about the importance of them taking more responsibility for their own health. Students were surprised at how strongly environmental risk factors such as poor diet, alcohol consumption, smoking, and over-exposure to sun were associated with cancer. One student wrote, "The most important [thing] I learned is to keep good health because by looking at the risk factors you can tell that everything that caused cancer was something bad to the health."

Acting on Information About Cancer helped students recognize that the results of scientific research can provide support for or against statutes intended to protect personal and public health. Students applied their understanding of science to discuss issues such as the degree to which society should govern the health practices of individuals. Students explained that good choices could reduce an individual's risk of developing cancer and could improve an individual's chance of survival if he or she did develop it.

Students were particularly aware of the link between ultraviolet light (UV) and skin cancer and their ability to reduce UV exposure by applying sunscreen and wearing protective clothing. A student wrote, "People can make their own decisions, therefore, they can prevent cancer to some extent." Another student added, "If you learn how to protect yourself better your risk of getting cancer can be lowered." Even students with very limited ability recognized this link. As one wrote, "People should be careful about exposing themselves." Another student elaborated, "By covering 90% of the body you are reducing the amount of UV exposure." Overall, students' responses suggested that they were willing to use sunscreen, wear hats, and wear sunglasses in order to reduce their personal cancer risks.

Disease Detectives provided an opportunity for students to consider ways to take more responsibility for their own health both individually and by working as a member of a community. Students collected a variety of evidence about environmental factors that might be involved in the spread of a disease. Students were very sensitive to the impact of environmental change on the emergence of new diseases. Students identified an important reason for the emergence of new diseases, namely, "because we humans interfere with nature and the environment. We build dams and houses in a animals habitat and take over the land and make things worst." Upon completing *Disease Detectives*, many students expressed opposition to "messing around with the environment" through encroachment into wilderness areas and increased human traffic through previously isolated areas. One wrote, "Try to prevent invading many animals habitats and try not to build dams and other inteffernce with the environment." Overall, students recognized that public health is affected by community actions as well as by personal decisions and were able to specify factors that could increase the risk of diseases becoming epidemics.

Summary of Answers to 6 Evaluation Questions.

The pilot evaluation provided empirical and anecdotal evidence that the curriculum supplements (1) promote higher science achievement; (2) reduce academic inequity; (3) stimulate student interest in medical topics; (4) deepen students' understanding of the importance of basic research to advances in medicine and health; (5) foster student analysis of the direct and indirect effects of scientific discoveries on their individual lives and on public health; and (6) encourage students to take more responsibility for their own health.

Science Achievement. Science achievement was significantly higher in classes where teachers taught at least 3 of the curriculum supplements. The curriculum supplements also appear to increase achievement indirectly by encouraging teachers to implement instructional practices recommended in the National Science Education Standards. Science achievement was higher in classes where teachers used the Standards-based *5E* pedagogical model.

Science Equity. Although science achievement of majority students was higher than that of minority students in all classes, the gap in academic achievement was smaller in classes where teachers used the curriculum supplements. Benefits of using the curriculum supplements may be due in part to changes in teacher practices that occur when the curriculum supplements are implemented as intended. Science achievement was more equitable in classrooms where teachers emphasized science engagement and active, inquiry-based learning.

There is evidence that the NIH science curriculum supplements may be particularly useful for improving achievement of minority students who attend disadvantaged schools. Accessibility to cutting-edge science curriculum and instruction historically is most limited for students at greatest risk of low achievement. By disseminating free curriculum supplements that increase accessibility to Standards-based science education opportunities nationwide, the NIH may promote academic equity.

Student Interest in Medical Topics. The curriculum supplement activities stimulated student interest in medical topics. There is some evidence that greater student interest in medical topics motivated students to learn more science even when the work was hard for them. There is some empirical evidence and much anecdotal evidence to suggest that interested students were more likely to do better on tests of science achievement and were more likely to recognize how science research was connected to their lives.

Students Understanding of the Importance of Basic Research. Each of the curriculum supplements contain activities that helped deepen students' understanding of the importance of basic research to advances in medicine and health. In particular, students demonstrated greater understanding of (1) how the basic biology of cancer can help us make sense of the many observations people have made about risk factors related to cancer; (2) the contribution that epidemiology has made to our understanding of cancer and the emergence and re-emergence of infectious diseases; (3) different ways that basic research can lead to advances in medicine and health that offer a variety of strategies for alleviating suffering due to infectious diseases; (4) how advances in science and technology can be used help detect or diagnose disease; (5) contributions that scientists studying human genetic variation at the molecular level are making to modern medicine; (6) how research in genetics across the last century has contributed to clinical medicine and changed how physicians diagnose and treat human diseases; (7) some of the ways scientists use molecular information to improve disease treatment; and (8) how understanding the molecular structure of a disease-related gene can help scientists develop new strategies for treating the disease.

Student Analysis of the Direct and Indirect Effects of Scientific Discoveries. The curriculum supplements helped students apply creative and critical thinking skills to analyze the direct and indirect effects of scientific discoveries on their individual lives and on public health. In so doing, students applied the same systematic and rigorous criteria used by scientists, namely, evaluation of the source, certainty, and reasonableness of the supporting information. Teachers attributed differences in student behaviors to the high levels of student engagement with and interest in the topics presented in the curriculum supplements.

Student Responsibility for Their Health. The curriculum supplement activities encouraged students to take more responsibility for their own health. Students recognized relationships between their behaviors and health risks and reported that they would use this knowledge to choose healthier, more active lifestyles and to take control of their health. Students were able to explain how behavioral choices affect not only an individual's risk of developing a disease but also their chance of survival if they do develop it. Some activities also helped students take more responsibility for public health by considering the impact of their personal decisions and community actions on the emergence or re-emergence of infectious diseases.

Unanticipated Findings: Factors that Affect Use of the Curriculum Supplements.

About 40% of the teachers who were randomly assigned to teach the curriculum supplement units taught only 1 or 2 activities. Three reasons teachers gave for not using the curriculum supplement were (1) the activities did not cover the objectives tested on the state science assessment; (2) the activities took too long to teach or took too much time away from other things they needed to cover; and (3) the reading and language were too sophisticated for their students.

Coverage. The paramount concern of all teachers, including those who taught in the comparison classes, was to "cover" content that would be tested on the state standardized assessment (the "*Regents*" exam). This was true even though some of the questions on the Regents measure student understanding of the nature of science and science process skills such as interpreting data from a graph, drawing inferences, synthesizing information, and using evidence to support claims. Teachers were unlikely to use the supplements if they perceived that the content was not directly tied to state assessments.

The focus on lesson content affected the way some teachers delivered instruction. Some teachers "covered" the activities but did not consistently use strategies that supported active, collaborative, and inquiry-based learning. A teacher at a small private school reported that she "loved" the supplement on Human Genetic Variation and sent copies of detailed lecture notes she created from it. In some classes students' responses to specific workbook questions were identical; the teachers appear to have focused more telling students the "right" answers than on providing ongoing feedback to students about the adequacy of their explanations and understandings. A teacher assigned to teach Emerging and Re-emerging Infectious Diseases at a disadvantaged school in Brooklyn reported that she liked that "the teachers had lesson plans laid out for them which included background information" but did not complete activities that emphasized science process skills because that meant "too much time had to be spent on the unit." Instead of using the pedagogical practices described in the curriculum supplements, these teachers partially adapted instruction to convert some activities into ones that fit their current teaching strategies.

The evaluation provides anecdotal evidence that suggests that teachers are resistant to changing their preferred teaching styles, or do not believe that science should be taught as inquiry, or do not have the skills or background to teach science as inquiry. This finding has implications for teacher training efforts that may strengthen the potential of the curriculum supplements as vehicles for informing and changing teacher practice and supporting science education reforms.

Activity length. Each curriculum supplement contains a section called *Implementing the Module* that, among other things, outlines a plan for preparing for and completing the 5 curriculum supplement activities in 5 or 6 consecutive days. Teachers were unanimous in their evaluation that the curriculum supplements took 3 or 4 times longer to teach than that. Pilot teachers who taught all 5 activities took a month or more to do so. Several pilot teachers who completed only 1 or 2 activities explained that implementation was incomplete because they needed to adhere to the 5-day time frame they had allocated to teach the curriculum supplements. Three factors that contributed to the discrepancy in estimates of activity length were the short length of the class period (typically 40 minutes each), the complexity of the activities, and the unfamiliarity of students and teachers with the *5E* approach.

A teacher from a disadvantaged school in Manhattan reported, “The activities are a great supplement, but forty minutes is not enough time to complete an activity in a thorough manner.... Next year I will teach double periods with the new Living Environment curriculum and these activities would be perfect because of the extended class time.” Reports such as these are consistent with those from teachers who field-tested the curriculum supplements and the conclusions of the field test evaluation. Developers of future curriculum supplements may use these results to produce more realistic estimates of the amount of time needed to teach the curriculum supplement activities.

Activity Difficulty. The curriculum supplement activities were designed to be complex and challenging. Some teachers thought the activities were too difficult for their students even when students were clearly engaged in them. One teacher who taught only 2 activities from the supplement on Human Genetic Variation (*Alike, But Not the Sam*e and *Are You Susceptible?*) wrote, "Both activities were fun and simple, really getting the point across [but] the questions were difficult. The wording was much more sophisticated than what my students are capable of understanding. After decoding the vocabulary for them, the students were able to answer the questions, but only with a lot of prodding." It is interesting to note that, while her students were slightly below average in ability, the difference between them and other students in the pilot sample was not statistically significant. The issue may not be what students are "capable of understanding" but rather the effect of teacher expectations on instructional choices. Future training that helps teachers understand how to use the supplements with students of all abilities may promote greater implementation of the curriculum supplements.

Discussion.

Results of this pilot evaluation document the potential of the curriculum supplements for helping students (1) understand a set of basic scientific principles; (2) experience the process of inquiry and develop an enhanced understanding of the nature and methods of science; and (3) recognize the role of science in society and the relationship between basic science and personal and public health. Findings support NIH decisions to continue to commit funds to develop nine additional curriculum supplements scheduled for national distribution beginning in 2001 and can be used to (1) guide future curriculum supplement development, particularly in terms of refining estimates of the amount of time needed to teach the curriculum supplement activities; (2) guide future teacher training efforts designed to promote greater implementation of the curriculum supplements as vehicles for informing and changing teacher practice and supporting science education reforms; (3) strengthen designs of future curriculum supplement evaluations planned for other geographic regions of the United States; and (4) inform discussions by the broader scientific and educational research community about national science education policy.

APPENDIX A: RESULTS OF HLM ANALYSIS

This evaluation design used a widely accepted multilevel statistical technique, hierarchical linear modeling (HLM) to measure the impact of the curriculum supplements on students in different classes. HLM estimated the impact of using the curriculum supplements in terms of value-added effects. Value-added indices assess program effectiveness after controlling for contributory variables such as aptitude, race-ethnicity, and gender. Without adjusting class means to account for some students being more- or less-advantaged than others, classes with higher concentrations of majority students of above average ability would have been more likely to have higher average achievement scores at the end of a unit regardless of whether their teachers used the curriculum supplements or not. Using a value-added approach "leveled the playing field" and allowed meaningful class comparisons.

Preliminary HLM analysis (not shown in a table) revealed that approximately 52% of the variance in science achievement was between classes, a finding that supported use of a multilevel model of student achievement. Table A shows the results of three student characteristics--gender (intercept $\beta 1$), minority status (intercept $\beta 2$), and aptitude (intercept $\beta 3$)--on the adjusted average science achievement for all classes (intercept $\gamma 00$). Tables B through G show the effects ($\gamma p1$) of curriculum supplement implementation[9] or of implementing individual activities[10] that emphasize one of the 5 phases of the *5E* pedagogical model on science achievement (intercept $\gamma 00$) and on academic equity (intercepts $\gamma 10$, $\gamma 20$, and $\gamma 30$).

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[9] Curriculum supplement implementation is a dichotomous variable with values of 1 or 0 depending on whether teachers met the minimum requirements for implementation (1) or not (0).

[10] Engage, explore, explain, elaborate, and evaluate are continuous, standardized variables derived from analysis of student workbook data that reflect whether, and to what extent, teachers taught the curriculum supplement activity most strongly representative of that respective phase of the *5E* model.

Table A: Effects of Gender, Minority Status, and Aptitude on Science Achievement.

Data presented in Table A show the average science achievement score for all classes (49.1) and differences in science achievement associated with demographic status. On average, science achievement of females was 6% higher than that of males, minority students scored 11% lower than majority students, and students who rated one SD above average in aptitude did 28% better than average students. There were significant differences among classes in achievement even after student demographic status and aptitude were controlled.

Table A
Effects of Gender, Minority Status, and Aptitude on Science Achievement

Fixed Effect	β Coefficient	SE	*t*-ratio	df	*p*	ES[11]	% Difference[12]
Class Achievement							
γ00 intercept	49.090907	0.79902	61.438	33	0.000		
Female							
β1 intercept	0.793616	0.599666	1.323	606	0.186	0.12	6%
Minority							
β2 intercept	-1.429670	0.694833	-2.058	606	0.039	-.21	-11%
Aptitude							
β3 intercept	3.874573	0.415708	9.320	606	0.000	.56	28%
Random Effect[13]	SD	Variance		df		Chi-square	*p*-value
τ U0	4.31184	18.59193		33		306.95258	0.000
σ^2_R	6.61870	43.80715					
Deviance = 4100.19479							
Deviance Change from Fully Unconditional Model = 77.96							

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[11] The ES for a slope coefficient describing students' characteristics is equal to the value of the beta (β) estimated by the unconditional model (shown in Table A) divided by the pooled within-group SD estimated by a model with no predictors (SD = 6.8785; model is not shown). The formula is: ES = β/6.8785.

[12] A percentage difference is equal to the ES divided by 2 times 100. The formula is: % = ES/2 * 100.

[13] Preliminary HLM analysis indicated that random effects were not significant for slopes describing the effects of student characteristics on achievement. The HLM was respecified as a random-intercept model and slope coefficients were allowed to vary non-randomly.

Table B: Effects of the Curriculum Supplement on Science Achievement and Equity.

Data presented in Table B show the effect of curriculum supplement implementation on science achievement. Implementation was defined as teaching at least 3 of the curriculum supplement activities. On average, science achievement was 15% higher in classes where teachers met this minimum requirement. Curriculum supplement implementation also was associated with more equitable science achievement. Compared to students whose teachers did not use the curriculum supplements, science achievement of females was 10% closer to that of males and minority achievement was 16% closer to that of majority students. When students of equal aptitude were compared, science achievement was 14% higher for students whose teachers taught the curriculum supplements.

Table B
Effects of Curriculum Supplement (CS) Implementation on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.069923	0.801453	61.226	32	0.000		
γ01 CS implementation	1.240252	1.747308	0.710	32	0.483	.29[14]	15 %
Female							
γ10 intercept	0.741674	0.603565	1.229	602	0.219		
γ11 CS implementation	-0.755338	1.376557	-0.549	602	0.583	-.20[15]	-10 %
Minority							
γ20 intercept	-1.432003	0.698596	-2.050	602	0.040		
γ21 CS implementation	1.547096	1.494071	1.035	602	0.301	.32	16 %
Aptitude							
γ30 intercept	3.881483	0.419722	9.248	602	0.000		
γ31 CS implementation	0.833992	0.963616	0.865	602	0.387	.27	14 %
Random Effect	SD		Variance	df	Chi-square		*p*-value
τ U0	4.30500		18.53299	32	289.18931		0.000
σ^2_R	6.62794		43.92964				

[14] The ES for a random intercept is equal to the value of the gamma divided by the SD of the intercept estimated in unconditional model (shown in Table A). The formula is: ES = γ/4.31.

[15] The ES for a slope coefficient describing a classroom characteristic is equal to the value of the gamma coefficient divided by the SD of the β coefficient in the unconditional model (shown in Table A). The SD of a β coefficient is equal to the standard error times the square root of the sample size, N. In this analysis, the sample size, N, is 34 classes. The formula is: ES = γ /(SE β * sqrt(34)).

Table C: Effects of Engagement on Science Achievement and Equity.

The *Engage* phase of the *5E* model initiates the learning sequence and introduces the major topic to be studied. Its primary purpose is to capture the students' attention and interest. The activity is designed to make connections between past and present learning experiences and to anticipate upcoming activities. By completing it, students should become mentally engaged in the unit and intrigued by the concepts they are about to study in depth.

Data presented in Table C show that science achievement was 9% higher in classes where teachers' emphasis on engagement was one SD above average. Emphasizing engagement was also associated with a significant reduction in the minority gap in achievement. In science classes where teacher emphasis on engagement was one SD above average, science achievement of minority students was 18% higher than was science achievement of minority students whose teachers' emphasis on engagement was average.

Table C
Effects of Engagement on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.134028	0.845467	58.115	32	0.000		
γ01 Engagement	0.784682	0.971650	0.808	32	0.425	0.18	9%
Female							
γ10 intercept	0.653306	0.616956	1.059	602	0.290		
γ11 Engagement	-0.192267	0.661919	-0.290	602	0.771	-0.05	-3%
Minority							
γ20 intercept	-1.524073	0.704794	-2.162	602	0.030		
γ21 Engagement	1.777436	0.666410	2.667	602	0.008	0.37	18%
Aptitude							
γ30 intercept	3.805843	0.539682	7.052	602	0.000		
γ31 Engagement	0.128381	0.509443	0.252	602	0.801	0.04	2%

Random Effect	SD	Variance	df	Chi-square	*p*-value
τ U0	4.32903	18.74054	32	298.46215	0.000
σ^2_R	6.60539	43.63124			

Table D: Effects of Exploration on Science Achievement and Equity.

In the *Explore* phase of the *5E* model students ask and answer questions about the topic and use resources to explore a topic in greater detail. The teacher provides students with ample opportunities for developing their own understanding of observations and phenomena but does not provide answers or lead students to solutions.

Data presented in Table D show that science achievement increased by 6% for every one SD increase in teacher emphasis on exploration. Emphasizing exploration was also associated with more equitable science achievement. In science classes where teacher emphasis on exploration was one SD above average, science achievement of females was 7% closer to that of males and minority achievement was 13% closer to that of majority students.

Table D
Effects of Exploration (Explore) on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.104263	0.806491	60.886	32	0.000		
γ01 Explore	0.471760	0.883512	0.534	32	0.597	0.11	6%
Female							
γ10 intercept	0.657090	0.607925	1.081	602	0.280		
γ11 Explore	-0.529353	0.745804	-0.710	602	0.478	-0.14	-7%
Minority							
γ20 intercept	-1.494422	0.701424	-2.131	602	0.033		
γ21 Explore	1.282774	0.741035	1.731	602	0.083	0.26	13%
Aptitude							
γ30 intercept	3.829143	0.419201	9.134	602	0.000		
γ31 Explore	0.097354	0.481775	0.202	602	0.840	0.03	2%

Random Effect	SD	Variance	df	Chi-square	*p*-value
τ U0	4.34058	18.84061	32	295.83852	0.000
σ^2_R	6.61950	43.81776			

Table E: Effects of Explanation on Science Achievement and Equity.

During the *Explain* phase of the *5E* model, students develop more detailed sets of explanations for the concepts they have been exploring. Explain activities give students opportunities to explain concepts in their own words or to demonstrate particular skills or behaviors. Typically, this is where the teacher introduces relevant terms and definitions, and where students might do some assigned reading about defined topics. However, activities remain student-centered. The teacher's role is to ask for justification and clarification that supports students' explanations, not to tell students "the answers."

Data presented in Table E show that science achievement increased by 6% for every one SD increase in teacher emphasis on developing detailed explanations. Emphasizing explanations was also associated with a significant reduction in the minority gap in achievement. In science classes where teacher emphasis on explanations was one SD above average, science achievement of minority students was 12% higher than that of minority students in classes where teachers used a more traditional approach.

Table E
Effects of Explanation (Explain) on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.082538	0.803100	61.116	32	0.000		
γ01 Explain	0.461350	0.943933	0.489	32	0.628	0.11	6%
Female							
γ10 intercept	0.717457	0.602702	1.190	602	0.234		
γ11 Explain	-0.047543	0.681499	-0.070	602	0.945	-0.01	-1%
Minority							
γ20 intercept	-1.549849	0.700677	-2.212	602	0.027		
γ21 Explain	1.178022	0.733383	1.606	602	0.108	0.24	12%
Aptitude							
γ30 intercept	3.823678	0.417453	9.160	602	0.000		
γ31 Explain	-0.171741	0.487896	-0.352	602	0.725	-0.06	-3%
Random Effect	SD		Variance	df	Chi-square		*p*-value
τ U0	4.33279		18.77310	32	297.41826		0.000
σ^2_R	6.62150		43.84420				

Table F: Effects of Elaboration on Science Achievement and Equity.

In the Elaborate phase of the *5E* model, students extend their understanding of a topic. Students attack a new set of questions and experiences to develop a broader understanding of the topic, obtain more information about areas of interest, and refine their scientific and critical thinking skills. A teacher's primary goal in this phase of the model is to help students articulate generalizations and extensions of concepts and understandings that are relevant to their lives.

Data presented in Table F show that science achievement was 1% higher in classes where teachers emphasized elaboration through laboratory investigation. When students of equal aptitude were compared, science achievement was 21% higher for students whose teachers placed one SD more emphasis on elaboration than did traditional teachers.

Table F
Effects of Elaboration through Laboratory Inquiry (Elaborate) on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.126158	0.837090	58.687	32	0.000		
γ01 Elaborate	0.106276	0.960972	0.111	32	0.913	0.02	1%
Female							
γ10 intercept	0.732137	0.641510	1.141	602	0.254		
γ11 Elaborate	0.119539	0.733541	0.163	602	0.871	0.03	1%
Minority							
γ20 intercept	-1.532745	0.771362	-1.987	602	0.047		
γ21 Elaborate	1.298203	0.665637	1.950	602	0.051	0.02	1%
Aptitude							
γ30 intercept	3.896467	0.519455	7.501	602	0.000		
γ31 Elaborate	0.444455	0.461192	0.964	602	0.336	0.42	21%

Random Effect	SD	Variance	df	Chi-square	*p*-value
τ U0	4.32485	18.70430	32	296.37430	0.000
σ^2_R	6.61911	43.81265			

Table G: Effects of Evaluation on Science Achievement and Equity.

The *Evaluate* phase of the *5E* model provides students with opportunities to use their understanding to solve real-world problems. Here it is important that students receive feedback on the adequacy of their explanations and understandings. Evaluate activities are complex and challenging and stretch students' abilities to listen, think, and speak.

Data presented in Table G show that science achievement was 17% higher in classes where teachers emphasized evaluation. Emphasizing evaluation was also associated with more equitable science achievement. In science classes where teacher emphasis on evaluation was one SD above average, science achievement of females was 6% closer to that of males and minority achievement was 12% closer to that of majority students. When students of equal aptitude were compared, science achievement was 5% higher for students whose teachers placed one SD more emphasis than average on evaluation.

Table G
Effects of Problem Solving and Evaluation (Evaluate) on Science Achievement and Equity

Fixed Effect	γ Coefficient	SE	*t*-ratio	df	*p*	ES	% Difference
Class Achievement							
γ00 intercept	49.057742	0.790743	62.040	32	0.000		
γ01 Evaluate	1.461472	0.984495	1.484	32	0.147	0.34	17%
Female							
γ10 intercept	0.742837	0.601266	1.235	602	0.217		
γ11 Evaluate	-0.459876	0.692082	-0.664	602	0.506	-0.12	-6%
Minority							
γ20 intercept	-1.509140	0.702316	-2.149	602	0.031		
γ21 Evaluate	1.154000	0.779733	1.480	602	0.139	0.24	12%
Aptitude							
γ30 intercept	3.801077	0.418925	9.073	602	0.000		
γ31 Evaluate	0.286513	0.512756	0.559	602	0.576	0.09	5%
Random Effect	SD		Variance	df	Chi-square		*p*-value
τ U0	4.20431		17.67625	32	276.96613		0.000
σ^2_R	6.61962		43.81938				