Executive Summary

At no time in history has improving science education been more important than it is today. Major policy debates about such topics as cloning, the potential of alternative fuels, and the use of biometric information to fight terrorism require a scientifically informed citizenry as never before in the nation's history. Yet after 15 years of focused standards-based reform, improvements in U.S. science education are modest at best, and comparisons show that U.S. students fare poorly in comparison with students in other countries. In addition, gaps in achievement persist between majority group students and both economically disadvantaged and non-Asian minority students. In part, these achievement gaps mirror inequities in science education and take on greater significance with the looming mandate of the No Child Left Behind Act that states assess science beginning in the 2006-2007 school year. Thus, science education in the United States has become a subject of grave and pressing concern.

The charge to this committee was to answer three broad questions: (1) How is science learned, and are there critical stages in children's development of scientific concepts? (2) How should science be taught in K-8 classrooms? (3) What research is needed to increase understanding about how students learn science?

Our answers to the first question are embodied in our conclusions. Our answers to the second question are embodied in our recommendations. We also offer recommendations on professional development, a topic that demands attention because of its relationship to the second question: how science is taught ultimately depends on the teachers. Extensive rethinking of how teachers are prepared before they begin teaching and as they continue teaching—and as science changes—is critical to improving K-8 science education in the United States.

PROFICIENCY IN SCIENCE

Underlying all our conclusions and recommendations is a redefinition of and a new framework for what it means to be proficient in science. This framework rests on a view of science as both a body of knowledge and an evidence-based, model-building enterprise that continually extends, refines, and revises knowledge. This framework moves beyond a focus on the dichotomy between either content knowledge or process skills because content and process are inextricably linked in science.

Students who are proficient in science:

1. know, use, and interpret scientific explanations of the natural world;
2. generate and evaluate scientific evidence and explanations;
3. understand the nature and development of scientific knowledge; and
4. participate productively in scientific practices and discourse.

These strands of proficiency represent learning goals for students as well as a broad framework for curriculum design. They address the knowledge and reasoning skills that students must acquire to be proficient in science and, ultimately, able to participate in society as educated citizens. They also incorporate the scientific practices that students need to demonstrate their proficiency. The process of achieving proficiency in science involves all four strands—advances in one strand support and advance those in another.

CONCLUSIONS: WHAT CHILDREN KNOW AND HOW THEY LEARN

Changes in understanding of what children know and how they learn have been profound in the past several decades. This new understanding is central to formulating how science should be taught. In summary:

- Children entering school already have substantial knowledge of the natural world, much of which is implicit.
- What children are capable of at a particular age is the result of a complex interplay among maturation, experience, and instruction. What is developmentally appropriate is not a simple function of age or grade, but rather is largely contingent on their prior opportunities to learn.
- Students' knowledge and experience play a critical role in their science learning, influencing all four strands of science understanding.

• Race and ethnicity, language, culture, gender, and socioeconomic status are among the factors that influence the knowledge and experience children bring to the classroom.
• Students learn science by actively engaging in the practices of science.
• A range of instructional approaches is necessary as part of a full development of science proficiency.

The commonly held view that young children are concrete and simplistic thinkers is outmoded; research shows that children's thinking is surprisingly sophisticated. Yet much current science education is based on the old assumptions and so focuses on what children cannot do rather than what they can do. Children can use a wide range of reasoning processes that form the underpinnings of scientific thinking, even though their experience is variable and they have much more to learn.

Contrary to conceptions of development held 30 or 40 years ago, young children can think both concretely and abstractly. As with most human characteristics, there is variation across children at a given age and even variation within an individual child. Development is not a kind of inevitable unfolding in which one simply waits until a child is cognitively "ready" for abstract or theory-based forms of content. Instead, parents and teachers can assist children's learning, building on their early capacities. Adults play a central role in promoting children's curiosity and persistence by directing their attention, structuring their experiences, supporting their learning attempts, and regulating the complexity and difficulty of levels of information for them. In the sciences, both teachers and peers can and must fill these critical roles.

Children's rich but naïve understandings of the natural world can be built on to develop their understandings of scientific concepts. At the same time, their understandings of the world sometimes contradict scientific explanations and pose obstacles to learning science. It is thus critical that children's prior knowledge is taken into account in designing instruction that capitalizes on the leverage points and adequately addresses potential areas of misunderstanding. To be successful in science, students need carefully structured experiences, instructional support from teachers, and opportunities for sustained engagement with the same set of ideas over weeks, months, and even years.

Children's experience varies with their cultural, linguistic, and economic background. Such differences mean that students arrive in the classroom with varying levels of exposure to science and varying degrees of comfort with the norms of scientific practice. These differences require teachers' sensitivity to cultural and other background differences and their willingness and skill to adjust instruction in light of these differences. Adjusting for variation in students' background and experience does not mean dumbing down the science curriculum or instruction. All children bring basic reasoning skills, personal knowledge of the natural world, and curiosity, which can be built on to achieve proficiency in science.

At present, a variety of factors result in inequities in science education that limit the opportunities for many students to learn science. Classroom-level factors related to instruction, such as teachers' expectations or strategies for grouping students, play a role in producing inequitable learning opportunities for economically disadvantaged and minority children. At the school, district, state, and federal levels, inequities in the quality of instruction and the qualifications of teachers, resources, facilities, and time devoted to science result in widely different learning opportunities for different groups of students. These inequities demand attention from policy makers, education leaders, and school administrators, as well as researchers.

Students' knowledge growth and reasoning are components of a large ensemble of activities that constitute "doing science." These activities include conducting investigations; sharing ideas with peers; specialized ways of talking and writing; mechanical, mathematical, and computer-based modeling; and development of representations of phenomena. To develop proficiency in science, students must have the opportunity to participate in this full range of activities.

Instruction occurs in sequences of designed, strategic encounters between students and science. Any given unit of study may include episodes that are highly teacher-directed as well as structured student-led activities. Across time, quality instruction should promote a sense of science as a process of building and improving knowledge and understanding. Students should have experiences in generating researchable questions, designing methods of answering them, conducting data analysis, and debating interpretations of data.

RECOMMENDATIONS: WHAT, WHEN, AND HOW TO TEACH

Our recommendations for standards, curricula, assessment, and instruction follow from our conclusions. However, in some areas the research base is not robust enough to offer a detailed, step-by-step roadmap for nationwide action. Given the urgent need for improvement in science education, the committee focused on the "best bets" that represent the most promising work. They require additional documentation through continued research and careful evaluation of implementation: by evaluating school, district, and state initiatives, these best bets can be transformed into well-researched alternatives for policy and practice. Our specific recommendations for research are in Chapter 11.

Science standards, curriculum, assessment, and instruction—as well as professional development for teachers—should be conceived of, designed, and implemented as a coordinated system. Standards and curriculum should lay out specific, coherent goals for important scientific ideas and practices that can be realized through sustained instruction over several years of K-8 schooling. Assessment should provide teachers and students with timely feedback about students' knowledge that, in turn, supports teachers' efforts to improve instruction. Teacher preparation and professional development should be focused on developing teachers' knowledge of the science they teach, how students learn science, and specific methods and technologies that support science learning for all students.

Recommendation 1: Developers of standards, curriculum, and assessment should revise their frameworks to reflect new models of children's thinking and take better advantage of children's capabilities.

Currently, standards and many widely used curriculum materials fail to reflect what is now known about children's thinking, particularly the cognitive capabilities of younger children.

Recommendation 2: The next generation of standards and curricula at both the national and state levels should be structured to identify a few core ideas in a discipline and elaborate how those ideas can be cumulatively developed over grades K-8.

Focusing on core ideas requires eliminating ideas that are not central to the development of science understanding. Core ideas should be both foundational in terms of connection to many related scientific concepts and have the potential for sustained exploration at increasingly sophisticated levels across grades K-8. Although existing national and state standards have been a critical first step in narrowing the focus of science in grades K-8, they do not go far enough. Future revisions to the national standards—and the subsequent interpretation of these standards at the state and local levels and by curriculum developers—need to be built around core scientific ideas and clearly identify the knowledge and practices that can be developed in science education over K-8.

Recommendation 3: Developers of curricula and standards should present science as a process of building theories and models using evidence, checking them for internal consistency and coherence, and testing them empirically. Discussions of scientific methodology should be introduced in the context of pur-

suing specific questions and issues rather than as templates or invariant recipes.

The processes and methodology that students encounter in the classroom need to reflect the range of investigatory forms in science. The range of methodology needs to include not only experiments, which have traditionally been the focus of school science, but also examples from scientific work that uses observational methods, historical reconstruction and analysis, and other nonexperimental methods.

Recommendation 4: Science instruction should provide opportunities for students to engage in all four strands of science proficiency.

In order to provide meaningful opportunities for science learning, policy makers, education leaders, and school administrators need to ensure that adequate time and resources are provided for science instruction at all grade levels for all students. They must also ensure that teachers have adequate knowledge of science content and process and are provided with adequate professional development.

Recommendation 5: State and local leaders in science education should provide teachers with models of classroom instruction that provide opportunities for interaction in the classroom, where students carry out investigations and talk and write about their observations of phenomena, their emerging understanding of scientific ideas, and ways to test them.

RECOMMENDATIONS: PROFESSIONAL DEVELOPMENT

Professional development is key to supporting effective science instruction. We call for a dramatic departure from current professional development practice, both in scope and kind. Teachers need opportunities to deepen their knowledge of the science content of the K-8 curriculum. They also need opportunities to learn how students learn science and how to teach it. They need to know how children's understanding of core ideas in science builds across K-8, not just at a given grade or grade band. They need to learn about the conceptual ideas that students have in the earliest grades and their ideas about science itself. They need to learn how to assess children's developing ideas over time and how to interpret and respond (instructionally) to the results of assessment. In sum, teachers need opportunities to learn how to teach science as an integrated body of knowledge and practice—to teach for scientific proficiency. They need to learn how to teach science to diverse student populations, to provide adequate opportunities for all students to learn science. These needs represent a significant change from what virtually all active teachers learned in college and what most colleges teach aspiring teachers today.

Recommendation 6: State and local school systems should ensure that all K-8 teachers experience sustained science-specific professional development in preparation and while in service. Professional development should be rooted in the science that teachers teach and should include opportunities to learn about science, about current research on how children learn science, and about how to teach science.

Recommendation 7: University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in the four strands that constitute science proficiency and giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K-8 curriculum.

Recommendation 8: Federal agencies that support professional development should require that the programs they fund incorporate models of instruction that combine the four strands of science proficiency, focus on core ideas in science, and enhance teachers' science content knowledge, knowledge of how students learn science, and knowledge of how to teach science.

In Chapter 11 the committee offers its recommendations for research—the work that should begin now to inform the future recommendations for science teaching.

To improve science education in the United States, changes are urgently needed throughout the system. Beginning with what is known about how children learn science, changes in teaching and in the education of teachers can and should begin now.