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ABSTRACT

The Georgia Learning Framework is a collaborative effort among community-based partners and professional educators to produce a vision of mathematics and science that will prepare all Georgia students for the 21st century. It identifies habits of mind, skills and knowledge, and dispositions that all students must possess to be productive citizens. Part 1 includes an introduction and discussion of the roles of students and teachers and transformations of mathematics and science. Part 2 presents goals for mathematics, science, and technology education. Also discussed in this section are the nature of mathematics; relating mathematics, the NCTM Standards, and Georgia students; dimensions of learning, including habits of mind, big ideas, and vehicles for understanding and doing; the nature of science; scientific view, inquiry, and enterprise; habits of mind from a scientific point of view; and scientific big ideas. Part 3 discusses how science and mathematics should be taught; how people learn new ideas; what instructional model can be used to achieve conceptual change; teaching tasks; discourse; teaching environments; and assessment. (Contains 36 references.) (MKR)

GEORGIA FRAMEWORK FOR LEARNING MATHEMATICS AND SCIENCE

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GEORGIA FRAMEWORK FOR LEARNING MATHEMATICS AND SCIENCE

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The **Georgia Initiative in Mathematics and Science** is funded in part by the National Science Foundation. The production of The Georgia Framework for Learning Mathematics and Science was partially supported under the Eisenhower Act for the Improvement of Mathematics and Science Education under the Higher Education Section of P.L. 100-297 Title II as administered by the U. S. Department of Education. The findings and opinions expressed herein do not necessarily reflect the position or policies of the National Science Foundation or the U. S. Department of Education.

Part I

Setting the Stage

The significant problems we face cannot be solved at the same level of thinking we were at when we created them. [1]

In Georgia, teachers of mathematics and science, mathematicians, scientists, administrators, parents, students, representatives from business and industry, and community leaders have embarked upon an educational journey to develop a framework for mathematics and science. The **Learning Framework** is the first articulated connection between national education standards[2] and learning experiences of all Georgia students. It communicates a philosophical foundation for the mathematics and science education for all Georgia students.

As education reform matures and more about this journey is clear and sure, the **Learning Framework** will be joined by other resources to form a **Learning and Teaching Portfolio,** supporting reform in mathematics and science education in Georgia. The **Learning Framework** and the other entries in the **Learning and Teaching Portfolio** will be presented to the State Superintendent of Schools and to the Georgia Board of Education for approval and adoption.

The Georgia **Learning Framework** is a collaborative effort among community-based partners and professional educators to produce a vision of mathematics and science that will prepare all Georgia students for the twenty-first century. It contains habits of mind, skills and knowledge, and dispositions that all students must possess to be productive citizens in the twenty-first century. It provides for access to mathematics and science experiences, and it articulates high expectations for every Georgia student.

The **Learning Framework** is a dynamic and adaptable document. It is designed to accommodate changes that will occur as more is understood about the nature of science and mathematics. It is designed to evolve with input from both community partners and educators to meet the needs of each Georgia student in the decades ahead.

The **Learning Framework** provides a frame of reference for planning and implementing transformations in mathematics and science education opportunities for every student in Georgia. Use of the **Learning Framework** by professional educators and the community demonstrates the realization of a shared vision of mathematics and science education in Georgia. In this vision, every student has access to a scientific and mathematical education that provides the opportunity to practice the habits of the discipline -- solving problems, thinking critically, reflecting upon thoughts and actions, and communicating effectively.

The **Learning Framework** highlights instructional practices, materials, and documentation strategies. These strategies support the notion that each child learns in different ways, at different rates, and for different reasons. These differences must not only be acknowledged, but celebrated, as Georgians redefine science and mathematics education for the twenty-first century. The **Learning Framework** sets the stage for redefining mathematics and science as it:

- describes a culture of learning that values each individual student
- affirms schooling as a community endeavor
- conveys a shared vision of mathematics and science education for all students in Georgia
- describes fundamental understandings of mathematics and science
- presents examples of high-quality instruction and assessment
- guides the selection, development, and management of learning resources
- offers guidelines for physical environments that support learning mathematics and science
- recognizes the richness of connections among and patterns within mathematics, science, and other disciplines
- connects the preparation and professional development of education professionals with the vision of mathematics and science education in Georgia
- advocates a system of support to move toward the vision

The vision of mathematics and science education must be tailored to the needs and characteristics of individual learners. We must articulate our vision, and we must make it clear that we are speaking about all learners.

Role of the Learner

A new and different view of knowledge and learning is emerging. In this view, the learner actively constructs new knowledge based on previous experience. Knowledge is built as individual learners acquire information through their senses and as they relate that information to their present range of experiences.

Knowledge and learning are personal experiences for the individual. These personal experiences will be varied and unique to each learner. Knowledge then consists of ideas that are viable in terms of the learner's present range of experience. Because of the various ways in which students create their own understanding, it is incumbent upon all educators to deliver instruction in diverse and multi dimensional ways.

Our assumptions about the nature of learners are that:

- **Learners require developmentally appropriate experiences to maximize the benefit of instruction.**

  Youngsters are an active, questioning, blossoming group. At the middle-grades level, learners are just beginning to reason logically and can understand hypothetical ("what if") scenarios. Their attention span may be rather short, and require that they be given varied activities to keep their attention. Coupled with this characterization is the notion that the different ways in which learners construct their own understanding of something contributes dramatically to the need to have alternative ways of presenting material and alternative ways of engaging learners in study.

- **Learners require active participation in learning experiences.**

  > *"I hear and I forget. I see and I remember. I do and I understand."*

  A modern twist on the above ancient Chinese proverb, found in the original research by Glasser on thinking and memory,[3] brings modern day meaning to the importance of active participation in learning. Minnesota Mining and Manufacturing research found that people remember 10 percent of what they hear, 30 percent of what they see, 70 percent of what they see and hear, and 90 percent of what they do.

Role of the Teacher

Teachers of mathematics and science must inspire each student to achieve at high levels. As teachers recognize students' diverse and multiple ways of learning, the role of the teacher changes. A shift must be made from teacher-centered instruction to learner-centered instruction. Teachers then become facilitators of mathematics and science learning. And, as facilitators of learning, teachers must provide every student with new experiences upon which to build new knowledge on the foundation of existing knowledge. Teachers must acknowledge that students construct their own knowledge. They must understand how students construct their own knowledge. And they must understand how each student recognizes and understands his or her own learning experience. Teachers must create environments, implement strategies, and select teaching and learning resources that will maximize learning for each student.

Transformation of Mathematics and Science

Coupled with assumptions about how students learn and how teachers facilitate learning are two basic understandings about change. First, basic skills for the twenty-first century are more than computation and memorization of facts, definitions, rules, and algorithms. Second, change in science and mathematics instruction at any one point in the K-16 sequence causes a fundamental shift that requires adjustments at all other levels. Just as we are calling for a transformation in the way scientific and mathematical literacy is defined, so too are we calling for this transformation to permeate education at all levels.

We begin by thinking about the transformation of our own understandings of the science and mathematics learning opportunities that Georgia students must have to fully participate in our democratic society. We must address the what, when, why, and how of science and mathematics teaching and learning. We initiate this transformation by rethinking our questions about learners.

- **Do we respect learners as individuals?**
- **Do we respect learners as learners?**
- **Do we believe that all learners respond positively to success and enthusiasm?**
- **Do we believe that all learners are curious and desire to learn?**
- **Do we believe that all learners learn by being actively involved, by taking risks, and by making connections?**

- Do we believe that all learners develop at different rates?
- Do we believe that all learners learn at different rates?
- Do we believe that all learners demonstrate learning in different ways?
- Do we believe that all learners can learn at high levels?

We must support the beginnings of this transformation by rethinking our beliefs about schools and classrooms as well.

- Do we believe that successful schools are for learners?
- Do we believe that schools must expect and communicate high levels of achievement?
- Do we believe that successful schools must provide time and instruction to achieve student success?
- Do we believe that successful schools must provide connections with home and community experiences?
- Do we believe that successful schools must ensure a safe, positive environment for all?
- Do we believe that successful schools must create opportunities to explore and grow?
- Do we believe that schools must provide more opportunities for learners?
- Do we believe that schools must provide more opportunities for teachers?
- Do we believe that good teaching must be recognized and celebrated?
- Do we believe that effective teachers are as valuable as effective professionals in medicine, law, engineering, and accounting?

If we answer "yes" to these questions, then the culture of classrooms and schools must change. The nature and dispositions of those who influence, manage, and direct learning must change. We must expand upon our understanding of what science and mathematics are. We must believe that every child can learn mathematics and science, that every child needs to learn mathematics and science, and that every child has the right to learn science and mathematics.

PART II

Challenging All Students for Tomorrow's World

Economies, environments, and technologies around the world are becoming increasingly interconnected and interdependent. The preparation of Georgia citizens for success in the twenty-first century will require education to provide all students with skills and knowledge required for few in this twentieth century. Business and industry, with an eye to the future, demand that education provide all citizens with ways of thinking, of solving problems, and of making decisions that will equip them to adapt to changes and meet new challenges as competent consumers, competent employees, and competent employers. Success in this endeavor will enable Georgia's citizens not only to survive, but to flourish and lead.

The preparation of today's youth for tomorrow's world requires cooperation. Social, religious, governmental, and economic groups, as well as educational entities, must share a vision for education that meets rapidly changing expectations.

While schools and classrooms are the focus for much of the change that must be implemented, they are only one of many educational resources. It is essential that members of all segments of the community become active participants in the education of Georgia students. To paraphrase an African saying, it takes two people to create a child and a whole village to raise that child. Collaboration among community members and organizations and school systems is not new nor, is it unique, but it is fundamentally important and imperative for success in Georgia.

Goals for Mathematics, Science, and Technology Education

> *....(T)here are certain thinking skills associated with science, mathematics, and technology that young people need to develop during their school years. These are mostly, but not exclusively, mathematical and logical skills that are essential tools for both formal and informal learning and for a lifetime of participation in society as a whole.* [4]

As the transformation of mathematics and science education in Georgia begins to be defined in the most inclusive and wide-reaching sense, the goals must be well considered, supported by the community, and consistent with the larger view of education within the United States. Goals for mathematics, science, and technology for Georgia students must recognize emerging and evolving national and global needs and expectations. After all, we are not educating students just for life in Dalton, Valdosta, Columbus, Augusta, or any one particular Georgia community but for wherever our children may live and work as adults. Our young citizens must be competent and successful anywhere in the world!

Through these goals for science and mathematics education in Georgia, the values of the disciplines are made more explicit. Georgia students must be able to frame and answer questions. They must be able to make decisions based on knowledge and information. Georgia students must be able to appreciate the inherent logic underlying the disciplines of science and mathematics. Finally, Georgia students must be able to use their knowledge, technology, and skills to contribute to their communities.

Following are broad goals for mathematics, science, and technology education in Georgia; each is focused by questions that students might explore:

To develop each student's ability to identify and clarify questions and problems about the world

Does time have anything to do with the rotation of the planets?

To broaden each student's thinking skills for gathering information, answering questions, solving problems, and making decisions

How can anyone manage all the transactions at automatic teller machines all across this country?

Can information from previous earthquakes help predict future earthquakes?

To develop each student's understandings and habits of mind in mathematics and science

Should animals be used in medical research?

How can Newton's Laws of Motion be demonstrated?

To develop an appreciation of the history and nature of science and mathematics

When was the Golden Age of Mathematics and why was it considered in that way?

How might our world be different if Madame Curie had been born a generation later?

To foster each student's appropriate uses of technology within science and mathematics

When is an exact answer necessary or an approximate answer better?

To advance each student's appreciation for the potential role of mathematics and science in explaining the natural world and in addressing societal, including technological, concerns

What are the implications for our world of diminishing supplies of petroleum?

What criteria should be applied to determine the capacity of a particular landfill?

To ensure that each student understands and can use important science and mathematics

What are the important mathematics and science understandings needed to efficiently allocate resources to the various forms of mass transportation?

These broad goals and focusing questions are intended to evoke an understanding of the transformation of mathematics and science learning for all students. The transformation journey will be defined as educators meet the challenge of change and reform on a daily basis.

How to Use the Learning Framework

The ideas covered in the **Learning Framework** can be daunting to any teacher or school district that tries to incorporate all of the goals presented. It is not even intended that schools attempt to do so. Within the spirit of the rallying cry "Less is more,"[5] it is intended that teachers, schools and districts examine the full panoply of options presented in the text and charts. And, if viewed holistically through the capacity cube, the interrelatedness of the concepts and processes begins to make the understandings and skills attainable and reasonable. It is through a planned, reasoned process, choose to address those ideas that make the most sense in their setting and context. To be sure, teachers will find a myriad of overlap among the goals in the charts. This overlap was fully intended -- to show how all aspects of science interrelate and to give teachers alternate ways of dealing with the same content.

The Nature of Mathematics

Mathematics by nature is both a pure, theoretical adventure of the mind and a practical, applied science. This dichotomy explains the ability of the theoretical mathematician to "do mathematics for mathematics' sake" and the applied mathematician to "use mathematics as a tool" to solve real problems.

Mathematics has developed into an immense system comprising, according to Mathematical Reviews (1992), more than 60 categories of mathematical activity. Mathematical ideas have an unusually long life. The Babylonian solution for quadratic equations is as current and useful as it was 4,000 years ago. Like other sciences, mathematics reflects the laws of the material world around us and serves as a powerful instructional tool for our knowledge and understanding of nature. Mathematics is also characterized by its independence from the material world. The abstract nature of theoretical mathematics gave birth even in antiquity to the fundamental dichotomy of mathematics as an object of study and also as a tool for application.

Mathematical ideas are both enduring and expanding. New mathematical ideas are built on other, older mathematical ideas or propositions. An analogy can be made to "continuous improvement" where current practices (or in this case, ideas) can be improved upon, given new effort and time. Usually improvement does not occur without energy, and it typically does not occur quickly. Many problems are solved and new areas of mathematics are created by looking at problems in new ways.

In 1993, Andrew Wile, an American mathematician, proved Fermat's Last Theorem, first posed in 1637. This problem is simple to state. It says that there are no positive whole numbers that solve the equation $x^n + y^n = z^n$, where n is greater than 2. Where n = 2, solutions are easy to find. For example, $3^2 + 4^2 = 5^2$. In the case where n = 2, this algebra problem becomes the familiar Pythagorean Theorem of Geometry. Wile began to study this problem when he was ten. Building on the work of others and considering the problem from the point of view of a seemingly disparate field of mathematics related to elliptical curves, Wile posed a solution to this famous problem. The problem and the search for a solution focused Wile on a career in mathematics as it absorbed his youth.

When Wile offered a solution to Fermat's Last Theorem in 1993, news flashed on e-mail messages (computer mail) across the world. Almost instantaneously, mathematicians around the globe knew of the proposed proof and began questioning and exploring Wile's work. The spread of Wile's work via technology enabled rapid and global conversations.

Most of the mathematics that students encounter in school seems as theoretical at first glance as Fermat's Last Theorem seems to be. This is evidenced by the familiar question, "How will I ever use this?" It is important both to give students a glimpse into the theoretical nature of mathematics and to relate the mathematics that they are studying to their everyday lives.

By its nature, there are interrelations and connections among the areas of mathematics such as algebra and geometry. A common example is showing an inequality on the number line. Relating $40 < x < 60$ to a number line is an easy way to see such a relationship. Extending the number line to include negative numbers and relating "below zero" to temperature is an intuitive introduction and natural extension for elementary and middle-grades students.

Many hands-on manipulative models help students extend their understanding of operations and mathematical properties to the set of integers. Using mathematical structure and relating past knowledge and experiences to new knowledge and experiences encourage students to construct ideas and develop mathematical power.

On the applied side, most of the mathematics that students encounter do have practical uses. It is the stuff of applied mathematics that is used in fields such as telecommunications (satellites, fiber optics), transportation, engineering, and many others. Making connections between mathematics and the students' real world includes bringing in examples or projects across subject areas.

To answer questions such as "What's this stuff good for?" and "Who cares?", those who influence the structure, format, and content of science and mathematics learning should remember this advice:

> *"If you want to make a course interesting, then you should study something of interest."* [6]

The advice applies to all grade levels and to learning beyond the traditional years of schools as well. The "something of interest" often comes from students' real-world experiences and many times from other disciplines, science being one of the natural choices.

A central goal for all levels of mathematics education is the development of mathematical power for all students. Mathematical power includes acquiring an effective awareness of both the spirit and uses of mathematics and a growing understanding of the breadth of the mathematical sciences and their deep interconnecting principles. In particular, mathematical power includes the ability to explore, conjecture, and reason logically; to solve non-routine problems; to connect concepts within mathematics and between mathematics and real-world situations; and to read, write, listen, and speak mathematically. Acquiring mathematical power also includes the development of personal self-confidence and a disposition to pursue, access, and use quantitative and spatial information in solving problems and in making decisions. Students' flexibility, perseverance, interest, curiosity, and creativeness also affect the actualization of mathematical power.

Relating Mathematics, the NCTM Standards, and Georgia Students

By the very nature of mathematics, mathematical ideas build one upon the other. A child's mathematical development closely resembles mathematics' historical development. For example, first, children understand the natural (or counting) numbers. Extensions to higher-level operations are built on the basic understandings of addition and subtraction. Multiplication is first viewed as "repeated addition." By experiencing mathematical ideas, first intuitively with hands-on manipulatives, followed by extensions into more formal symbols, students relate ideas with the mathematics they encounter. By relating the child's world to the mathematics, there is reason to want to know.

The development of mathematical ideas becomes more sophisticated as students are developmentally ready for more advanced levels of abstraction. Early experiences in an informal setting build the foundation for more rigorous development in high school and later.

Mathematical ideas are introduced intuitively and informally and build as children are developmentally ready to understand the ideas from a more advanced level and as they are ready for more difficult concepts. An example of this development is in measurement and scale, from the infinitesimal to the gigantic. First, ideas of "how big" relate to one another using comparison. The objects initially may be very different in size, such as a mouse and an elephant. Piaget's "conservation" abilities do not occur developmentally until a certain maturity is reached. For example, a young child will judge a tall, slender glass to be "bigger" than a shorter glass of larger diameter, even if a liquid poured from the shorter glass fills the slender glass to over-flowing. Later, when the child is developmentally ready, volume measurement becomes meaningful. Further mathematical development will lead from an understanding of the exact relationship between the dimensions of a container and its volume to the ability to compare the volumes of hypothetical containers without a dependence on concrete models.

In order to be effective learning tools for children, instructional materials must be appropriate for them. Recognizing the change in sophistication of children's logical reasoning as they mature provides opportunity for aligning learning with developmental differences. For example, in the middle grades, most children comprehend "if, then" reasoning. This is an example of informal deduction. As these children mature and develop intellectually through high school, they begin to understand and use the rules of formal deductive reasoning. It would be inappropriate to present mathematical proofs based on formal rules of deductive reasoning to most middle-grade learners. Similarly, it would be inappropriate <u>not</u> to use formalized proofs in the teaching of high school students.

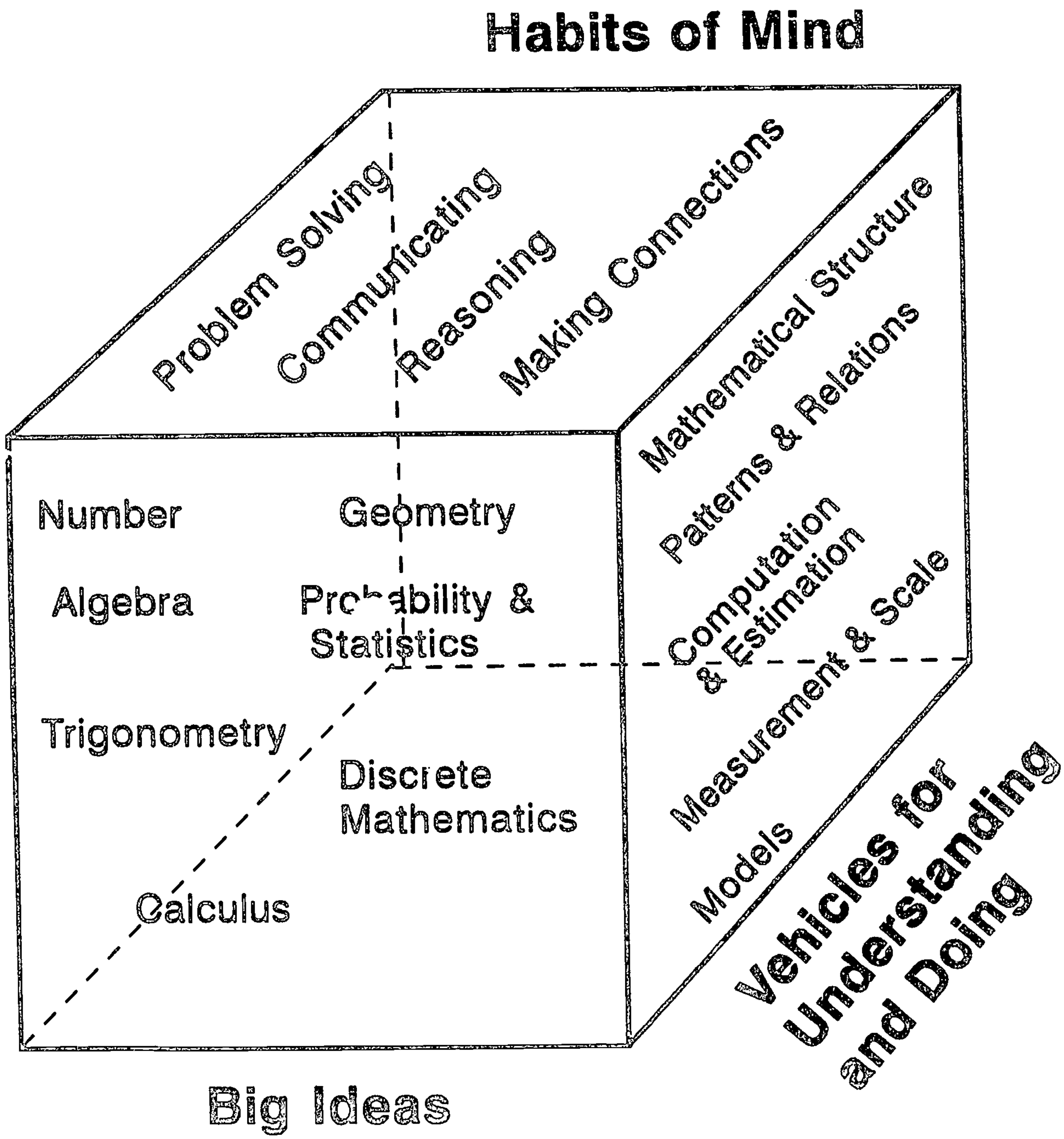
The mathematical "habits of mind" must increase in rigor and depth as learners develop through their school-based experiences. The values and capabilities that capture the essence of mathematical "thinkers and doers" in our world must be introduced when the schooling process begins and must be built upon and strengthened throughout formal schooling. Mathematical "thinking and doing" must become as natural for our children as listening, speaking, reading, and writing. Problem solving, reasoning, estimating, and the other mathematical habits of mind must be fluent capabilities for all children.

The National Council of Teachers of Mathematics in *Curriculum and Evaluation Standards for School Mathematics* (NCTM Standards) has proposed national standards defining what all children should know and do in their school development.[7] There are many interrelationships among and between the NCTM Standards. As teachers and students implement the standards, it may be useful to think of a model that acknowledges that learning is not linear and that the NCTM Standards relate to one another. Building relationships and associations and applying fundamental ways of "thinking and doing" are key to constructing meaningful knowledge.

Dimensions of Learning

The Capacity Cube is a way of thinking about how to implement these standards. Its purpose is to help focus teachers and learners on the interrelatedness of the standards and mathematical lessons. The Capacity Cube (C^3) presents the NCTM Standards organized into three categories: Habits of Mind, Vehicles for Understanding and Doing, and the Big Ideas of Mathematics.

The C^3 model highlights the mathematics that each student should understand, appreciate, and be able to use in meaningful ways in school and in life. The Capacity Cube is consistent with and supportive of the NCTM Standards. It is a graphic organization of the knowledge and process areas that are presented in the NCTM Standards. The Capacity Cube organizes these areas of knowledge and processes so that fundamental connections and integrations are explicit. Other connections and integrations will emerge as teachers work to move from the NCTM Standards as a document to the NCTM Standards as a way of thinking and doing for both teachers and students.


Habits of Mind
Problem Solving
Communicating
Reasoning
Making Connections
Mathematical Structure
Patterns & Relations
Computation & Estimation
Measurement & Scale
Models
Number
Geometry
Algebra
Probability & Statistics
Trigonometry
Discrete Mathematics
Calculus
Big Ideas
Vehicles for Understanding and Doing

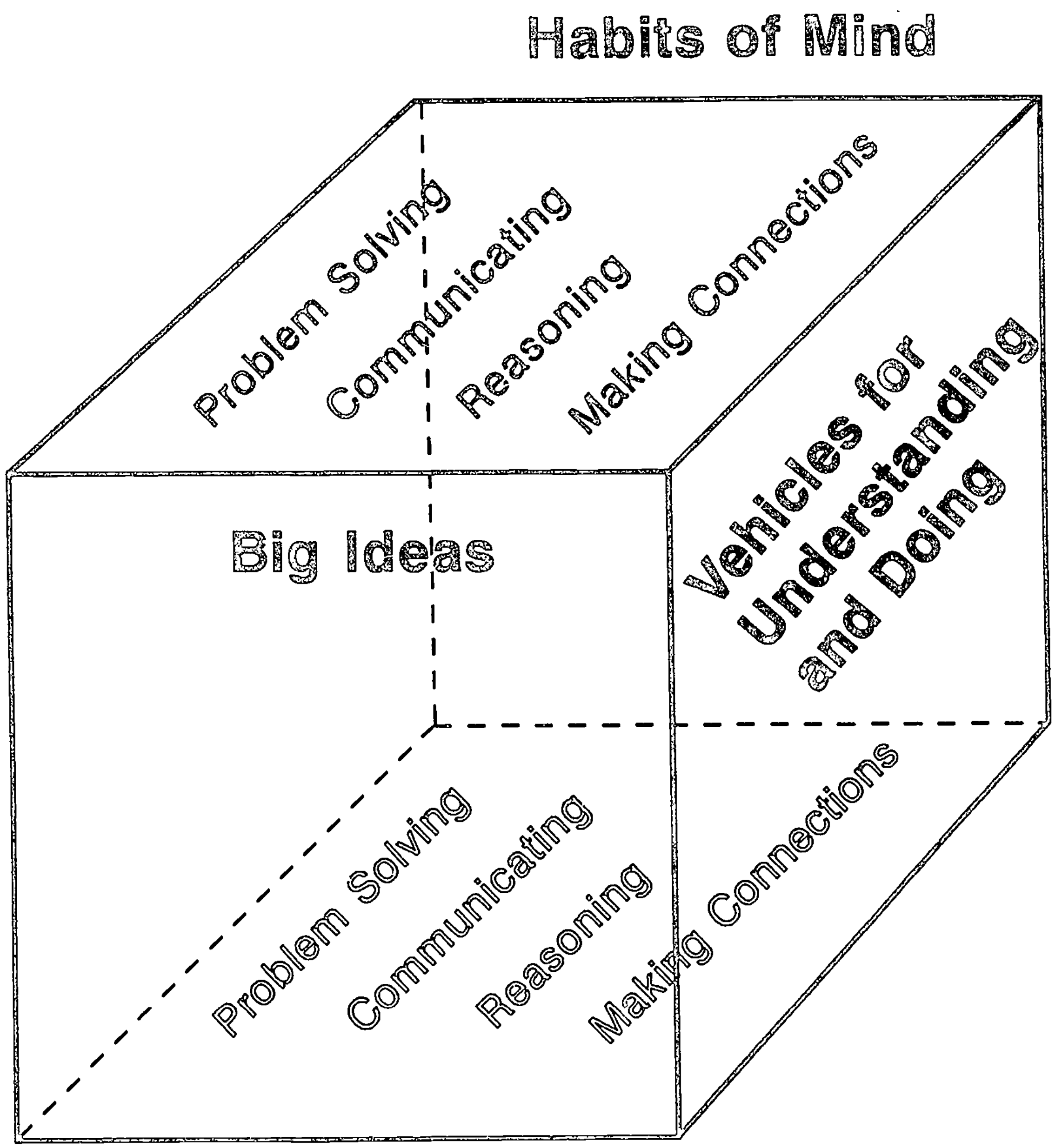
The "Habits of Mind" of Problem Solving, Communicating, Reasoning, and Making Connections are ways of thinking about problems and real world situations that may be geometric, algebraic, arithmetic, or probabilistic. The "Vehicles for Understanding and Doing" are meaningful ways to approach problems. The "Mathematical Big Ideas" are the culmination and refinement of mathematical thinking and are ideas that will help students make sense of and operate in their current and future lives.

When students construct mathematical ideas, all three faces of the cube are involved. Making the relationships for students who are actively involved in learning creates meaning and relevance in the mathematics.

Habits of Mind

The top of the cube represents the "Habits of Mind" that students should develop and represent both scientific and mathematical thinking. A habit is any activity that is so well established that it occurs without thought on the part of the individual. Habits of mind are those well-established thinking behaviors and disposition that are characteristic of methodical and logical thinking. The habits of mind represented are Problem Solving, Communicating, Reasoning, and Making Connections.

"To **solve a problem** is to find a way where no way is known off-hand, to find a way out of a difficulty, to find a way around an obstacle, to attain a desired end that is not immediately attainable, by appropriate means."[8] Problem situations for younger children arise from the real world and everyday experiences of the child ("Do you have enough money to buy your lunch and to pay for your yearbook?"). As students become more mathematically sophisticated, problem situations also spring from within mathematics itself ("Can the product of two prime numbers be a prime number?"). Problem solving is much more than applying specific techniques to the solution of a class of word problems. It is a process by which the fabric of mathematics as identified in later standards is both constructed and reinforced.


Habits of Mind
Problem Solving
Communicating
Reasoning
Making Connections
Big Ideas
Vehicles for Understanding and Doing
Problem Solving
Communicating
Reasoning
Making Connections

All students need extensive experience **communicating** mathematics, by listening to, reading about, writing about, speaking about, reflecting on, and demonstrating mathematical ideas. By incorporating communicating mathematics, teachers can direct instruction away from a focus on the recall of terminology and routine manipulation of symbols and procedures toward a deeper conceptual understanding of mathematics ("Janet, can you explain to Celia why you think the round pizzas are a better buy?").

Reasoning is fundamental to the knowing and doing of mathematics. Conjecturing and demonstrating the logical validity of conjectures are the essence of the creative act of doing mathematics. From the intuitive and concrete thinking of young children, reasoning and the development of logic become more formal as children develop higher levels of reasoning ability. The role of reasoning should be emphasized in all areas of mathematics ("If the square pizzas are larger, how can the round pizzas be a better buy?").

Students need to **make connections** among mathematics and other disciplines and across mathematical topics. Two general types of connections are important: (1) modeling connections between problem situations that may arise in the real world or in other disciplines ("How is our pizza problem like the carpet problem we worked on yesterday?" "Can you create a different problem that uses the same mathematical model?") and (2) mathematical connections between two or more equivalent representations and between the corresponding processes in each, that is, to begin to see mathematics as an integrated whole ("Melissa, can you think of another way we might approach this problem?" "Would a bar chart help?").

The habits of mind are not specific mathematical or scientific topics, but are ways of thinking that influence the way students approach their world. These "habits of mind" will be encouraged and encountered whenever discussions of other ideas or concepts occur.

Academic expectations for students in the four areas of Problem Solving, Communicating, Reasoning, and Making Connections are summarized across the grade levels in the following Table.

Table 1 - Habits of Mind

Level	Problem Solving	Communicating
Primary	Use problem-solving approaches to investigate and understand. Formulate problems from everyday situations. Develop and apply strategies to solve a wide variety of problems. Interpret results; relate to the original problem. Acquire confidence in using mathematics meaningfully.	Relate physical materials, pictures, drawings to mathematical ideas. Reflect on their thinking about mathematical situations. Relate everyday language to mathematical language and symbols. Represent, discuss, read, write, and listen to mathematics.
Elementary	Use problem-solving approaches to investigate and understand mathematical content. Formulate problems from everyday and mathematical situations. Develop and apply strategies to solve a wide variety of problems. Verify and interpret results with respect to the original problem situation. Acquire confidence in using mathematics meaningfully.	Relate physical materials, pictures, diagrams to mathematical ideas. Reflect on and clarify their thinking about mathematical ideas and situations. Relate everyday language to mathematical language and symbols. Recognize that representing, discussing, reading, writing, and listening to mathematics are vital parts of learning and using mathematics.
Middle Grades	Use problem-solving approaches to investigate and understand mathematical content. Formulate problems from situations within and outside mathematics. Develop and apply a variety of strategies to solve problems, with emphasis on multi-step and non-routine problems. Verify and interpret results with respect to the original problem situation. Generalize solutions and strategies to new problem situations. Acquire confidence in using mathematics meaningfully.	Model situations using oral, written, concrete, pictorial, graphical, and algebraic methods. Reflect on and clarify their own thinking about mathematical ideas and situations. Develop common understandings of mathematical ideas, including the role of definitions. Use the skills of reading, listening, and viewing to interpret and evaluate mathematical ideas. Discuss mathematical ideas and make conjectures and convincing arguments. Appreciate the value of mathematical notation and its role in the development of mathematical ideas.
Secondary	Use, with increasing confidence, problem-solving approaches to investigate and understand mathematical content. Apply integrated mathematical problem-solving strategies to solve problems from within and outside mathematics. Recognize and formulate problems from situations within and outside mathematics. Apply the process of mathematical modeling to real-world problem situations.	Reflect upon and clarify their thinking about mathematical ideas and relationships. Formulate mathematical definitions and express generalizations discovered through investigations. Express mathematical ideas by written and spoken word. Read written presentations of mathematics with understanding. Ask clarifying and extending questions related to mathematical concepts they have read or heard about. Appreciate the economy, power, and elegance of mathematical notation and its role in the development of mathematical ideas.

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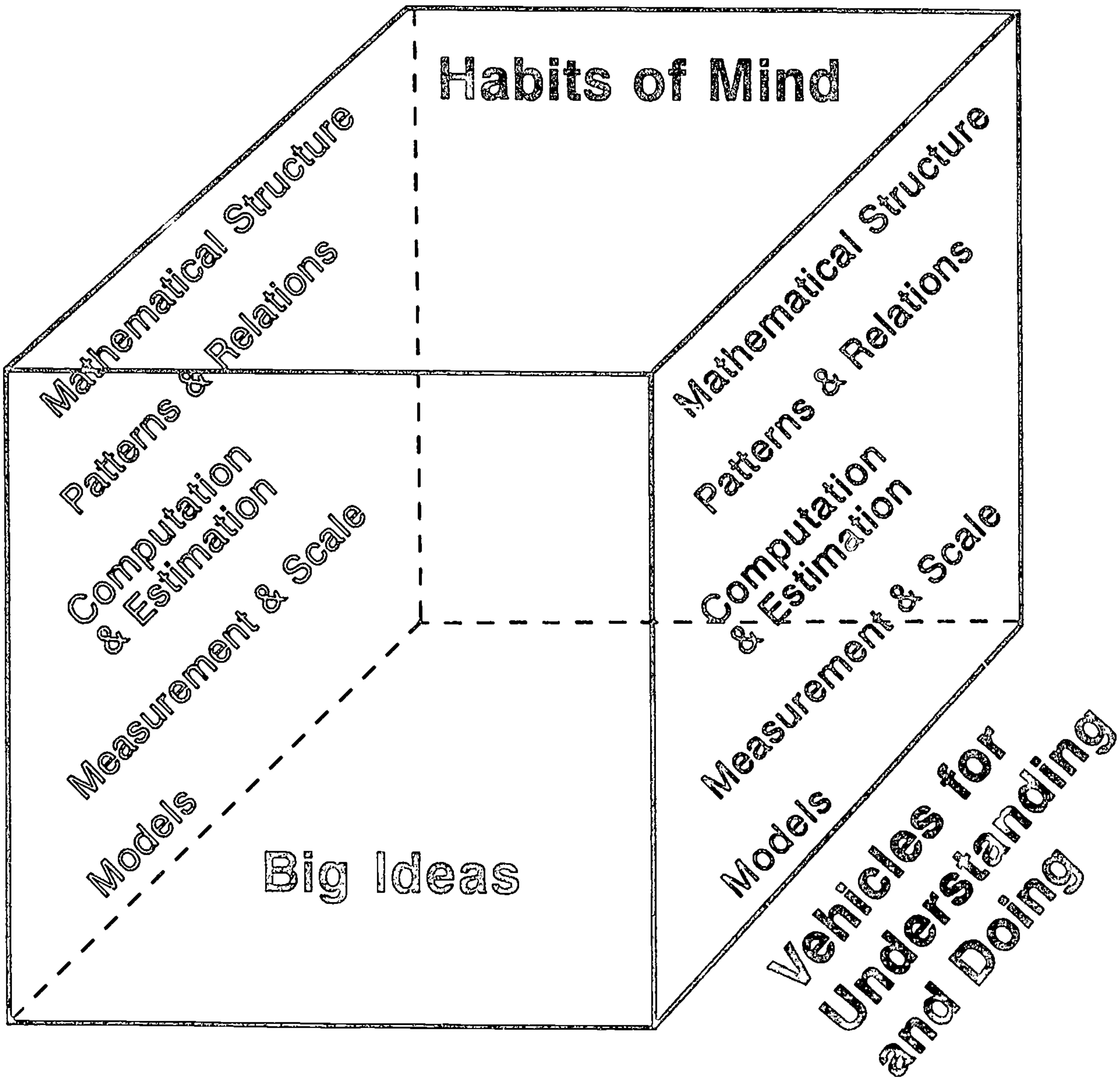
Table 1 - Habits of Mind (cont'd)

Level	Reasoning	Making Connections
Primary	Recognize common attributes within mathematics. Use models, facts, properties, and relationships to explain their thinking. Justify their answers and solutions processes. Use patterns to describe mathematical situations. See that mathematics makes sense.	Relate concepts and procedures within a mathematical context. Experience different ways of doing mathematics. Experience related topics in mathematics. Use mathematics in other curriculum areas. Use mathematics in their daily lives. .
Elementary	Draw logical conclusions about mathematics. Use models, known facts, properties, and relationships to explain their thinking. Justify their answers and solutions processes. Use patterns and relationships to analyze mathematical situations. Use intuition to judge mathematical situations. Believe that mathematics makes sense.	Link conceptual and procedural knowledge. Relate various representations of concepts or procedures to one another. Recognize relationships among different topics in mathematics. Apply mathematical thinking to everyday problems that arise. Use mathematics in other curriculum areas. Use mathematics in their daily lives.
Middle Grades	Recognize and apply deductive and inductive reasoning. Understand and apply reasoning processes, with special attention to spatial reasoning and reasoning with proportions and graphs. Make and evaluate mathematical conjectures and arguments. Begin logical reasoning. Experiment with and think about "what if..."and "then... scenarios. Validate their own thinking. Appreciate the pervasive use and power of reasoning as a part of mathematics.	See mathematics as an integrated whole. Explore problems and describe results using graphical, numerical, physical, algebraic, and verbal mathematical models. Use mathematical ideas to further understand other ideas. Apply mathematical thinking and modeling to solve problems from other disciplines, such as art, music, psychology, science and business. Value the role of mathematics in our culture and society.
Secondary	Make and test conjectures. Formulate counterexamples. Follow logical arguments. Judge the val. lity of arguments. Construct simple, valid arguments. *Note: For further extension and depth of understanding, students can* *Construct arguments for mathematical assertions, including indirect proofs and proofs by mathematical induction.*	Recognize equivalent representations of the same concept. Relate procedures in one representation to procedures in an equivalent representations Use and value the connections among mathematical topics. Use and value the connections between mathematics and other disciplines.

Vehicles for Understanding and Doing

A vehicle is anything through or by which something, such as thought, power, or information, is conveyed, transmitted, expressed, or achieved. The side face of the cube represents "Vehicles for Understanding and Doing." These are: Mathematical Structure, Patterns and Relations, Computation and Estimation, Measurement and Scale, and Models. These can be thought of as ways of seeing and relating ideas and as approaches to solving problems.



Mathematical Structure provides students with the mathematical tools necessary to design their own constructs for problem solving ("What do we know about the possible answer to this question? Can the answer be negative? Can it be a fraction? Can there be more than one answer?"). **Patterns and Relations** give students a mechanism for seeing and developing a variety of ways of approaching problems ("Do you see a pattern here? What do all of these numbers have in common? How are these two figures alike?"). **Computation and Estimation** are procedures for checking, supposing, visualizing, and setting parameters ("About how many one-inch cubes would fit in this box?" "Is the answer on your calculator consistent with your estimate?"). **Measurement and Scale** include measuring, and using ratio and proportion ("If John is four feet six inches tall, how tall should his picture be in our scale drawing?"). **Models** help students visualize mathematics when physical models are used to demonstrate mathematical properties or expressions. By using physical models (manipulatives), "hands-on" activities, and computer activities, students have concrete experiences with which to solve problems ("Arrange the centimeter cubes to illustrate all of the possible factors of twelve."). Mathematical models describe real-world problems and phenomena in science, social science, economics, architecture, and the like. For example, the equation of a line can model a real-world phenomenon such as CO_2 emissions from automobiles. Computers and other technological tools can be used to model complex phenomena such as the prediction of economic conditions around the world given certain conditions of supply and demand.

The "Vehicles for Understanding and Doing" presented in Table 2 are incorporated into investigations across many areas of mathematics and other disciplines. Similar to the "Habits of Mind," these are ways of doing and approaching problems and tools for problem solving activities in mathematics and other disciplines.

Table 2 - Vehicles for Understanding and Doing

Level	Mathematical Structure	Patterns & Relations
Primary	Apply counting skills to problem situations. Relate mathematical symbols to mathematical ideas, such as numbers and shapes. Understand the numeration system by relating counting, grouping, and place value. Relate subtraction to addition. Recognize relationship among different topics in mathematics. Develop operation sense.	Recognize, describe, extend, and create a wide variety of patterns. Recognize common attributes in a group of objects. Represent and describe mathematical relations. Explore the use of variables and open sentences to express relations.
Elementary	Extend the number system to include fractions, decimals, and integers. Relate algebraic ideas to geometric representations. Relate multiplication to addition, arrays, and cartesian products.. Relate division to subtraction and multiplication. Develop spatial relations. Investigate and predict the results of combining, separation, and changing shapes.	Recognize, describe, extend, and create a wide variety of patterns. Represent and describe mathematical relations. Explore the use of variables and open sentences to express relations.
Middle Grades	Extend the development of the number system through the use of integers. Understand how the basic arithmetic operations are related to one another. Apply logical reasoning. Recognize relationships among different topics in mathematics.	Describe, extend, analyze, and create a wide variety of patterns. Describe and represent relationships with tables, graphs, and rules. Analyze functional relationships to explain how a change in one quantity results in a change in another. Use patterns and functions to represent and solve problems.
Secondary	Compare and contrast the real number systems and its various sub-systems with regard to their structural characteristics. Understand the logic of algebraic procedures. Appreciate that seemingly different mathematical systems may be essentially the same. *Note: For further extension and depth of understanding, students can* *Develop the complex number system and demonstrate facility with its operations.* *Prove elementary theorems within various mathematical structures, such as groups and fields.* *Develop an understanding of the nature and purpose of axiomatic systems.*	Model real-world phenomena with a variety of functions. Represent and analyze relationships using tables, verbal rules, equations, and graphs. Translate among tabular, symbolic, and graphical representations of functions. Recognize that a variety of problem situations can be modeled by the same type of functions. Analyze the effects of parameter changes on the graphs of functions. *Note: For further extension and depth of understanding, students can* *Understand operations on, and the general properties and behavior of, classes of functions.*

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Table 2 - Vehicles for Understanding and Doing (cont'd)

Level	Computation & Estimation	Measurement & Scale
Primary	Use a variety of mental computation and estimation techniques. Use calculators in appropriate computational situations. Select and use computation techniques appropriate to specific problems. Develop concepts underlying "guessing" and explore estimation strategies. Recognize when an estimate is appropriate. Determine the reasonableness of results. Apply estimation in working with quantities, measurement, computation, and problem solving.	Understand the attributes of length, capacity, weight, area, volume, time, and temperature. Develop the process of measuring and concepts related to units of measurement. Make and use estimates of measurement. Make and use measurements in problem solving and everyday situations.
Elementary	Model, explain, and develop reasonable proficiency with basic facts and algorithms. Use a variety of mental computation and estimation techniques. Use calculators in appropriate computational situations. Select and use computation techniques appropriate to specific problems. Further develop concepts underlying "guess and test" so they can explore estimation strategies. Recognize when an estimate is appropriate. Determine the reasonableness of results. Apply estimation in working with quantities, measurement, computation, and problem solving.	Understand the attributes of length, capacity, weight, mass, area, volume, time, temperature, and angle. Develop the process of measuring and concepts related to units of measurement. Make and use estimates of measurement. Make and use measurements in problem solving and everyday situations.
Middle Grades	Compute with whole numbers, fractions, decimals, and integers. Develop, analyze, and explain procedures for computation and techniques for estimation. Develop, analyze and explain methods for solving proportions. Select and use an appropriate method for computing from among mental arithmetic, paper-and-pencil, calculator, and computer methods. Use computation, estimation, and proportions to solve problems. Use estimation to check the reasonableness of results.	Apply their understanding of the process of measuring. Estimate, make, and use measurements to describe and compare phenomena. Select appropriate units and tools to measure to the degree of accuracy required in a particular situation. Understand the structure and use of systems of measurements. Extend their understanding of the concepts of perimeter, area, volume, angle measure, capacity, and weight and mass. Develop the concepts of rates and other derived and indirect measurements. Use ratio and proportion to solve real-world problems. Develop formulas and procedures for determining measures to solve problems.
Secondary	Use computation and estimation to solve problems. Use estimation to check the reasonableness of results.	Apply measurement and scale to solving problems and to modelling mathematical ideas.

Table 2 - Vehicles for Understanding and Doing (cont'd)

Level	Models
Primary	Relate physical materials, pictures, and diagrams to mathematical ideas. Model, explain, and develop reasonable proficiency with basic facts and algorithms. Use physical models to represent addition and subtraction. Use physical models to represent fractions as parts of a whole as well as parts of a set. Use models to relate fractions to other equivalent fractions. Use models to explore operations on fractions. Use calculators and computers to explore operations, relations, patterns, and geometric shapes. Model geometric shapes.
Elementary	Model situations both written and spoken language using concrete, pictorial, graphical, and algebraic representations. Use models to demonstrate number operations. Use physical models to relate equivalent fractions and decimals. Construct number meanings through real-world experience and the use of physical materials. Develop meaning for the operations by modeling. Use physical models to represent fractions as parts of a whole as well as parts of a set. Use models to relate fractions to decimals and to find equivalent fractions. Use models to explore operations on fractions and decimals. Use calculators and computers to explore operations, relations, patterns, and geometric shapes. Represent and solve problems using geometric models.
Middle Grades	Use physical models to represent mathematical concepts. Use mathematical models to represent physical phenomena. Represent and solve problems using geometric models. Develop an appreciation of geometry as a means of describing the physical world. Model real-world situations by devising and carrying out experiments or simulations to determine probabilities. Model situations by constructing a sample space to determine probabilities. Appreciate the power of using a probability model by comparing experimental results with mathematical expectations. Develop confidences in solving linear equations using concrete, informal, and formal methods. Use calculator and computer simulations to model real-world phenomena. Use mathematical thinking and modeling to solve problems that arise in other disciplines such as art, music, psychology, science, and business.
Secondary	Use physical models to represent mathematical concepts. Use algebraic functions to model real-world phenomena. Use geometric models to describe real-world phenomena. Use trigonometric functions to model periodic real-world phenomena. Use models to make content connections. Use calculator and computer simulations to model real-world phenomena. Use mathematical thinking and modeling to solve problems that arise in other disciplines such as art, music, psychology, science, and business.

Mathematical Big Ideas

The front face of the cube represents "Big Ideas" in mathematics. Some of these big ideas are number, algebra, geometry, trigonometry, discrete mathematics, and calculus. These are the mathematical "big picture" topics that are appropriate for students to begin to investigate and understand. As a student develops mathematical concepts, the ideas build upon one another. Introductions in a hands-on and intuitive sense in the early years help build number sense and spatial sense, the ideas needed later for algebra and geometry. As students construct knowledge, they are later able to understand more formal, symbolic representations. Symbol manipulation without the foundation of understanding has little transfer to real problems and little utility.

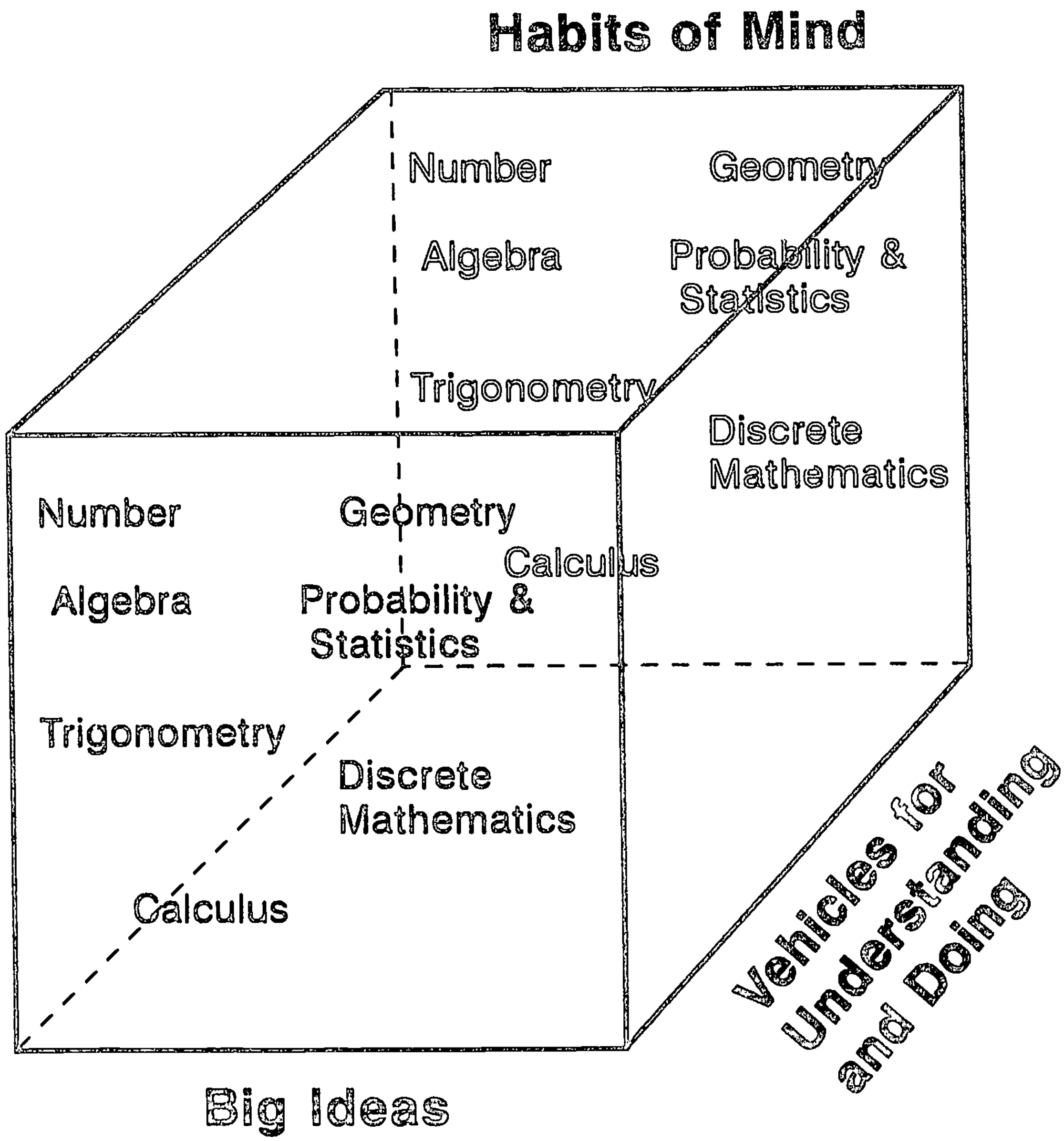

Table 3 summarizes the academic expectations for students organized within the "Big Ideas" across the grades: Primary, Elementary, Middle, and Se ondary levels.

Table 3 - Mathematical Big Ideas

Level	Number Sense, Numbers, and Operations
Primary	Construct number meanings through real-world experience and the use of physical materials Understand our numeration system by relating counting, grouping, and place value concepts. Develop number sense. Interpret the multiple uses of numbers encountered in the real world. Develop meaning for the operations by modeling and discussing a rich variety of problem situations. Relate the mathematical language and symbolism of operations to problem situations and informal language. Recognize that a wide variety of problem structures can be represented by a single operation. Develop operation sense. Identify fractions using physical models, both as parts of a whole and parts of a set. Identify regions divided into congruent parts. Develop concepts of fractions and mixed numbers. Develop number sense for fractions and decimals (money). Use models to relate fractions to other equivalent fractions and decimals (money). Use models to explore operations on fractions. Represent fractions and decimals with standard symbols. Apply fractions and decimals to problem situations, including money.
Elementary	Construct number meanings through real world experience and the use of physical materials. Understand our numeration system by relating counting, grouping, and place value concepts. Investigate whether numbers are odd or even, prime or composite. Compare numbers to each other in terms or greater than, less than or equal, and explore different representations of the same number. Develop number sense. Interpret the multiple uses of numbers encountered in the real world. Develop meaning for the operations by modeling and discussing a rich variety of problem situations. Relate the mathematical language and symbolism of operations to problem situations and informal language. Recognize that a wide variety of problem structures can be represented by a single operation. Develop operation sense. Develop concepts of fractions, mixed numbers and decimals. Develop number sense for fractions and decimals. Use models to relate fractions to decimals and to find equivalent fractions. Use models to explore operations on fractions and decimals. Apply fractions and decimals to problem situations.
Middle Grades	Understand, represent, and use numbers in a variety of equivalent forms (integer, fraction, decimal, percent, exponential, and scientific notation) in real-world and mathematical problems situations. Develop number sense for whole numbers, fractions and decimals (rational numbers), and integers. Develop the real number system . Understand and apply ratios, proportions, and percents in a wide variety of situations. Investigate relationships among fractions, decimals, and percents. Represent numerical relationships in one- and two-dimensional graphs. Understand and appreciate the need for numbers beyond the whole numbers. Develop and use order relations for whole numbers, fractions and decimals (rational numbers), and integers. Apply their understanding of whole number operations to fractions, decimals, and integers. Understand how the basic arithmetic operations are related to one another. Develop and apply number theory concepts (e.g., primes, factor, and multiples) in real-world and mathematical problem situations.
Secondary	Develop number sense for real number systems. Use complex numbers.

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Table 3 - Mathematical Big Ideas (cont'd)

Level	Geometry & Spatial Sense
Primary	Describe, sort, and classify shapes. Investigate the results of combining, and changing shapes. Construct two- and three-dimensional shapes with physical models. Identify and draw two- and three-dimensional shapes. Develop spatial sense. Recognize and appreciate geometry in their world.
Elementary	Describe, model, draw, and classify shapes. Investigate and predict the results of combining, subdividing, and changing shapes. Identify, describe, and draw lines, line segments, lines of symmetry, rays, angles, parallel and perpendicular lines. Identify and draw three-dimensional shapes. Develop spatial sense. Relate geometric ideas to number and measurement ideas. Determine when pairs of figures are congruent and similar. Recognize and appreciate geometry in their world.
Middle Grades	Identify, describe, compare, and classify geometric figures. Visualize and represent geometric figures with special attention to developing spatial sense. Explore transformations of geometric figures. Determine when pairs of figures are congruent and similar. Represent and solve problems using geometric models. Understand and apply geometric properties and relationships. Develop an appreciation of geometry as a means of describing the physical world.
Secondary	Interpret and draw two- and three-dimensional objects. Represent problem situations with geometric models and apply properties of figures. Classify figures in terms of congruence and similarity and apply these relationships. Deduce properties of, and relationships between, figures from given assumptions. Translate between synthetic and coordinate representations. Deduce properties of figures using transformations and using coordinates. Identify congruent and similar figures using transformations. Analyze properties of Euclidean transformations and relate translations to vectors. *Note: For further extension and depth of understanding, students can* *Develop an understanding of an axiomatic system through investigation and comparing various geometries.* *Deduce properties of figures using vectors.* *Apply transformations, coordinates, and vectors in problem solving.*

Table 3 - Mathematical Big Ideas (cont'd)

Level	Probability and Statistics
Primary	Collect, organize, and describe data. Construct, read, and interpret displays of data. Formulate and solve problems that involve collecting and analyzing data. Explore ideas of uncertainty and chance.
Elementary	Explore data analysis and probability. Collect, organize, and describe data. Construct, read, and interpret displays of data, including picture, bar, circle, and line graphs. Formulate and solve problems that involve collecting and analyzing data. Explore concepts of fairness, uncertainty, chance, and probability of an event.
Middle Grades	Systematically collect, organize, and describe data. Construct, read, and interpret tables, charts, and graphs. Make inferences and convincing arguments that are based on data analysis. Evaluate arguments that are based on data analysis. Develop an appreciation for statistical methods as powerful means for decision making. Model real-world situations by devising and carrying out experiments or simulations to determine probabilities. Model situations by constructing a sample space to determine probabilities. Appreciate the power of using a probability model by comparing experimental results with mathematical expectations. Make predictions that are based on experimental or theoretical probabilities. Develop an appreciation for the pervasive use of probability in the real world.
Secondary	Construct and draw inferences from charts, tables, and graphs that summarize data from real-world situations. Use curve fitting to predict from data. Understand and apply measures of central tendency, variability, and correlation. Understand sampling and recognize its role in statistical claims. Design a statistical experiment to study a problem, conduct the experiment, and interpret and communicate the outcomes. Analyze the effects of data transformations on measures of central tendency and variability. Use experimental or theoretical probability, as appropriate, to represent and solve problems involving uncertainty. Use simulations to estimate probabilities. Understand the concept of a random variable. Create and interpret discrete probability distributions. Describe, in general terms, the normal curve and use its properties to answer questions about sets of data that are assumed to be normally distributed. *Note: For further extension and depth of understanding, students can* *Transform data to aid in data interpretation and prediction.* *Test hypotheses using appropriate statistics.* *Apply the concept of a random variable to generate and interpret probability distributions including binomial, uniform, normal, and chi square.*

Table 3 - Mathematical Big Ideas (cont'd)

Level	Algebra	Discrete Mathematics
Primary	Relate mathematical symbols to mathematical ideas. Relate subtraction to addition. Develop operation sense. Recognize, extend, and create patterns. Explore the use of variables and open sentences to express relations.	Represent data graphically.
Elementary	Extend the number system to fractions, decimals, and integers. Relate algebraic ideas to geometric representation. Relate multiplication to addition, arrays, and Cartesian products. Relate division to subtraction and multiplication. Recognize and describe mathematical relations and functions. Explore the use of variables and open sentences to express relations. Use models to represent mathematical ideas.	Represent data in tables and graphs.
Middle Grades	Understand the concepts of variable, expression, and equation. Represent situations and number patterns with tables, graphs, verbal rule, and equations and explore the interrelationships of these representations. Analyze tables and graphs to identify properties and relationships. Develop confidence in solving linear equations using concrete, informal, and formal methods. Investigate inequalities and nonlinear equations informally. Apply algebraic methods to solve a variety of real-world and mathematical problems.	Represent data in tables and graphs. Exhibit relationships graphically.
Secondary	Represent situations that involve variable quantities with expressions, equations, inequalities, and matrices. Use tables and graphs as tools to interpret expressions, equations, and inequalities. Operate on expressions and matrices, and solve equations and inequalities. Appreciate the power of mathematical abstraction and symbolism. *Note: For further extension and depth of understanding, students can* *Use matrices to solve linear systems.* *Demonstrate technical facility with algebraic transformations, including techniques based on the theory of equations.*	Represent problem situations using discrete structures such as finite graphs, matrices, sequences, and recurrence relations. Represent and analyze finite graphs using matrices. Develop and analyze algorithms. Solve enumeration and finite probability problems. *Note: For further extension and depth of understanding, students can* *Represent and solve problems using linear programming and difference equations.* *Investigate problem situations that arise in connection with computer validation and the application of algorithms.*

Table 3 - Mathematical Big Ideas (cont'd)

Level	Trigonometry	Calculus Concepts
Primary	Recognize geometric shapes.	Relate numbers to points on a line.
Elementary	Apply notions of congruence and similarity.	Understand betweeness, closeness, and rounding.
Middle Grades	Investigate properties of triangles and develop connections among right triangle ratios.	Expanding the number system. Use relations and functions to describe phenomena and solve problems.
Secondary	Apply trigonometry to problem situations involving triangles. Explore periodic real-world phenomena using the sine and cosine functions. *Note: For further extension and depth of understanding, students can* *Understand the connection between trigonometric and circular functions. Use circular functions to model periodic real-world phenomena.* *Apply general graphing techniques to trigonometric functions.* *Solve trigonometric equations and verify trigonometric identities. Understand the connections between trigonometric functions and polar coordinates, complex numbers, and series.*	Determine the maximum and minimum points of a graph and interpret the results in problem situations. Investigate limiting processes by examining infinite sequences and series and area under curves. *Note: For further extension and depth of understanding, students can* *Understand the conceptual foundations of limit, the area under a curve, the rate of change, and the slope of a tangent line, and their applications in other disciplines.* *Analyze the graphs of polynomial, rational, radical, and transcendental functions.*

Using the Capacity Cube (C^3) Model

When planning and implementing the NCTM Standards in school mathematics, the cube model can ensure that students and teachers focus on higher-level reasoning, problem solving, and critical thinking as well as content objectives. Learning activities should not attempt to isolate one cell or one dimension of the Capacity Cube, but should emphasize the relationships, interactions, and interconnections of the dimensions. While a lesson may be designed to emphasize Reasoning in Geometry using rubber band Models, that same lesson will likely include Communicating Patterns, Reasoning, Measurement and Scale, and perhaps, elements of Trigonometry. This integrative approach will ensure that students are engaged in activities that are more than rote drill and practice, more than presentation of facts or rules. This integrative approach will also ensure that both teachers and students see the interrelatedness of the Standards and mathematics.

The Nature of Science

It goes without saying that today's world is not the same as the one of our grandparents, parents or, even that of our own childhood. Multiple changes, too numerous to list, have created a world that is increasingly complex and highly technical. Today's children must be prepared to flourish in such a world; they must be armed with the scientific attitudes, thinking abilities, and broad concepts that will serve them well in a future world that we cannot even imagine. At its core this implies that today's students must become scientifically literate. Thus, it is essential that they become creative problem solvers, critical thinkers, effective communicators, inquirers, and reflective learners.

The daunting task of preparing children for such an adventure is the responsibility of the science education community within Georgia. Critical to success in this venture is understanding that science at its roots is a human endeavor. The three principal aspects of science as a human endeavor are the scientific view, scientific inquiry, and the scientific enterprise itself.

Scientific View

The scientific view means that "scientists share certain basic beliefs and attitudes about what they do and how they view their work." [9] A basic tenet of this view is that scientific ideas are subject to change. This implies that an important purpose for science is producing new knowledge. While believing that scientific knowledge is tentative, scientists also consider most scientific knowledge as durable; that the modification of ideas, not their outright rejection, is the norm.

Lastly, this view implies that science cannot and should not try to supply answers to all questions. Science has limitations that are finite.

Scientific Inquiry

Scientific inquiry is the process by which scientists test, refine, and discover new ideas. It goes far beyond researching known scientific facts and information. At the heart of scientific inquiry are the processes of questioning -- asking what, why, and how -- and searching for answers for these questions. Scientific inquiry is also democratic, allowing independence and freedom of thought, and encouraging disagreement and alternative explanations. It is through these values that scientific ideas become understood, then accepted or rejected. These characteristics of scientific inquiry have important implications for the nature of science teaching and learning in all grades. Because inquiry is so essential to understanding the true nature of science, classroom environments must emphasize the inquiry that science itself stresses --

questioning, testing ideas, searching for alternative explanations, and allowing and even encouraging disagreement.

Scientific Enterprise

The scientific enterprise is a complex set of activities that influence and are influenced by the context in which the enterprise occurs. It is organized into various fields and disciplines to facilitate research and the communication of research findings. Participants in the scientific enterprise are expected to conduct themselves within the boundaries of ethical norms. Scientific knowledge is not created in a vacuum. A knowledge of history assists scientists by helping them avoid past errors and extend successes. It enables students to understand the cultural context in which scientific ideas were conceived, and what led to their acceptance or rejection in the scientific community, and in the community at large. A historical perspective also helps students to understand how science affects and changes culture. This knowledge is vital if students are to effectively address today's concerns as well as future concerns.

The sections that follow define and clarify the three dimensions of the capacity cube for science. The first major section discusses "Habits of Mind" from a scientific point of view. While these Habits of Mind are the same as those laid out in the mathematics section, certain nuances distinctive to science will be addressed and expanded upon. The section on "Vehicles for Understanding and Doing" lays out several cross-cutting and common themes for all the sciences. These themes spiral throughout all sciences and most grade levels. Lastly, the section entitled Scientific "Big Ideas" examines the major science content topics and understandings necessary for scientific literacy.

Habits of Mind from a Scientific Point of View

Science is more than a mere collection of facts or ideas. Science is a unique way of knowing that implies a particular manner of thinking and acting on the world. The "Habits of Mind" provide us with essential thinking skills which serve as tools for both formal and informal learning and for lifelong participation in society. We use the term "Habits of Mind" to describe this aspect of science. In essence, habits of mind are the essential tools necessary for formal and informal learning of science and for lifelong participation in our scientific world. The four major habits of mind are problem solving, reasoning, communication, and making connections. Each is described separately below.

Problem solving is a broad term encompassing many kinds of scientific inquiry. In some cases scientists ask questions, make accurate observations, collect and interpret data, and draw conclusions from their data. For example, an animal behaviorist can find out about how a particular organism reacts to stimuli by setting up a controlled experiment and making deductions from the results. This process, called experimenting, is sometimes considered the dominant way in which scientists find out about the natural world. Whether this is true or not (and this often depends on the particular scientific discipline), experimenting is certainly one of the most important aspects of scientific problem solving. A nuance of experimenting is that it is most often recursive in nature. It is not a one-time activity. That is, scientists often perform an experiment and get inconclusive results or even discover errors in their procedures. This then leads them to try again, to attempt to get more accurate, reliable, or valid data upon which to base conclusions. Yet other types of scientific inquiry are based on the processes of observation and inference. Naturalists often identify new species of plants and animals, not through experimentation, but rather through the power of observation. Theoretical physicists often create and build models and use their powers of inference to learn about physical systems. Likewise, paleontologists can make inferences about the environment of an ancient organism based on associated plant fossils. In each of these cases, however, scientists are solving problems by applying scientific problem-solving techniques.

Reasoning is closely related to problem solving, and stresses the use of data and logic to draw conclusions, create interpretations, and make decisions. Reasoning is used in all aspects of science. As field geologists observe a rock outcrop, they must decide whether the outcrop is a significant aspect of the field map being produced. To do so, they must reason from both textbook and practical knowledge as well as from experience of geology. Likewise, animal behaviorists use reasoning throughout their experiments. Is the procedure accurate? Does the data look reasonable? Are there any variables left uncontrolled? Without applying reasoning abilities, no scientist (or intelligent being for that matter!) could accomplish much.

Communication involves the sharing of data, observations, results, and interpretations via graphic representations and the written and spoken word. No one scientist can know or understand everything. Thus communication becomes a critical habit of mind for sharing information. Scientists communicate orally in person, by using the phone and other technology, and by attending professional meetings at which their work can be shared. They also communicate through journals, magazines, books, and other print materials. More recently, communication is becoming increasingly technologically based. Scientists create, share, and use large databases. They communicate using their computers and through interactive television. Regardless of the medium, however, regular and accurate communication is a key component of scientific advancement.

Making connections emphasizes how ideas in science are related to each other and to other experiences, both in the formal educational setting, but most importantly in everyday life experiences. The traditional disciplines of biology, chemistry, physics, and earth science are divisions created by scientist that allow for in-depth focus on a particular aspect of science. Yet these divisions by their very nature limit thinking. Making connections also implies the use of universal scientific process skills, laboratory techniques, and reasoning not only within all science disciplines, but in other fields as well. Scientifically literate individuals can apply these skills in many situations and often apply these scientific processes to solve problems on a daily basis. This habit of mind is also particularly important in solving real-world problems that overlap traditional scientific boundaries. For example, architectural engineers attempting to achieve the best acoustical qualities when designing an auditorium must understand the physics of sound.

Likewise, someone trying to improve the quality of paint for use by artists must know about how the human eye and brain interact to perceive color. These connections to other disciplines are critical to most successful science in today's world.

Table 4 summarizes the habits of mind addressed in the Learning Framework.

TABLE 4 - Habits of Mind

Level	Problem Solving	Communicating	Reasoning	Making Connections
Primary	Ask questions about the world. Seek answers to questions by observing and using trial and error.	Use various attributes to describe and compare objects. Draw pictures that show features of objects being described.	Ask and answer the questions, "How do I know?" and "How can I find out?"	Regard science as an integrated whole and a part of daily life. Make quantitative and qualitative estimates of various measurements. Use simple scientific instruments such as magnifiers and thermometers.
Elementary	Keep accurate records of investigations and observations. Suggest reasons for findings and consider findings of others. Ask scientific questions based on observation and experience. Plan and conduct a simple scientific investigation. Use data and experience to construct reasonable explanations.	Explain to others how to solve a simple problem. Make sketches to explain ideas, procedures, or results. Record data in a log, journal, or data base. Use simple reference materials to locate information. Read and interpret simple tables, charts, and graphs.	Use data to support inferences and predictions. Recognize biased comparisons. Use data, experience, evidence, and models to construct a reasonable explanation.	View the sciences in a holistic manner, not as discrete entities. Use simple mathematics to solve scientific problems. Use technological tools, such as calculators, computers and elementary scientific instruments in scientific, investigations. Explore how science relates to other disciplines and daily life.
Middle Grades	Identify appropriate questions for scientific investigation. Construct hypotheses to guide investigations. Design and conduct a scientific investigation. Draw conclusions and/or design a new scientific investigation based on results of a prior investigation. Realize that different conclusions can be drawn from the same data and that all may be correct.	Organize data into tables and charts and interpret. Read, construct and interpret bar and line graphs. Communicate scientific procedures, instructions and explanations. Use technology to communicate.	Question claims made without evidence or those based on small or biased samples. Compare products based on features, performance, durability, cost, and other characteristics. Think critically and logically about relationships between evidence and explanations. Recognize and analyze alternative explanations and procedures.	Identify how various living world and physical setting concepts interrelate. Use mathematics skills and processes in scientific investigations. Use appropriate scientific tools and technologies to gather, analyze and interpret data. Apply scientific reasoning to solve problems in other disciplines and daily life.

Table 4 - Habits of Mind (cont'd)

Level	Problem Solving	Communicating	Reasoning	Making Connections
High School	Devise and use algorithms for solving problems. Design and conduct a full scientific investigation. Identify questions and concepts building and underlying scientific investigations.	Make and interpret scale drawings. Summarize data graphically and verbally. Use tables, graphs, and charts in oral and written presentations. Communicate and defend a scientific argument. Use technology to manipulate and transmit data and findings.	Criticize arguments based on faulty use of data or logic. Use valid critical assumptions. Recognize and analyze alternative explanations and models. Construct and revise scientific explanations and models using logic and evidence.	Relate concepts and processes in the living world to those in the physical setting. Apply mathematics to scientific problems. Use advanced laboratory tools and technologies in scientific investigations. Relate scientific concepts and processes to those in other disciplines and daily life.

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Vehicles for Understanding and Doing

Vehicles for understanding and doing are the themes common to all science. Those selected for inclusion in this document come from *Benchmarks for Science Literacy*,[10] and include the unifying concepts and processes for grades K-12 described in the National Science Education Standards. [11] Four major themes are identified: Systems, Models, Constancy and Change, and Measurement and Scale. Each of these is described below. It should be understood, that the learnings important for scientifically literate individuals, might well be organized using a different set of them. This is just one model being used in this document.

Systems

A system is a group of objects, ideas, processes, and/or organisms that influence one another or function together. Systems are human creations that help people better understand their world. For example, it is easier to understand the digestive system, even in all its complexity, than it is to comprehend the entire system of the human body. For full understanding of the human body, an individual must know about all of the systems' parts, how they function and interact with other parts, and even how the entire system interacts with other systems. It is also sometimes useful to comprehend both the inputs to a system (energy into an ecosystem, for example) as well as its outputs (e.g., sound from a set of speakers).

Systems are functional and exhibit patterns of organization and hierarchy that are not random. For example, in the life sciences, cells make up tissues, which make up organs, which, in turn, fashion body systems. Thus, in order to understand how the digestive system processes a hamburger, french fries, and a soft drink into molecules that can be distributed to and used by individual cells, a student should know about the structure and function of each organ in the system, how these organs work together to accomplish the task, and how the various types of cells and tissues contribute to the process. Even each cell itself is a system made of many parts which must work together cooperatively to perform well the functions of the cell.

The purpose for which a system is created dictates the scope and size of that system. If a mechanic wishes to fix a car's air conditioning, then he or she might define the system as one which includes all of the mechanical and electrical components, including blowers, conduits, condensers, and electric controls. On the other hand, if the mechanic believes that the problem lies only in the electrical controls, then a much smaller (although still very complex) system can be defined. Thus, many systems are composed of smaller subsystems, with each subsystem having its own internal parts and interactions. Humanity itself can be considered a subsystem in some cases because the person is part of a complex economic system, for example, while at the same time being a system unto himself/herself. Furthermore, a person is composed of various subsystems.

Models

Models are simplified representations of objects, processes, or systems that help scientists understand and describe how things work. Models need not be accurate representations of phenomena, rather, they serve their purpose best when they facilitate understanding and learning. For example, the Bohr model of the atom is no longer considered to be an accurate representation of a real atom, yet it is helpful to younger students in understanding atomic theory.

Models can be physical, conceptual, or mathematical. Some physical models are devices that behave like the real thing, for example, a model car or airplane. Other physical models, referred to as "manipulatives," are used to simulate situations -- for example, gumdrops and toothpicks to simulate the atoms and bonds in a molecule. Conceptual models explain the unfamiliar by comparing it to something familiar and understood through imagery, metaphor, or analogy. Describing the flow of electricity through a conductor by comparing it to the plumbing system of a house is a conceptual model. Many times conceptual models do not fit all the attributes of the system that one is trying to understand. Sometimes a model is too simple; at other times only certain attributes of mathematical models describe how components of a system inter-relate. Equations used in the physical sciences are such models because they describe phenomena such as force, current and energy mathematically.

Well into the middle grades, students need to work primarily with physical models first and then with conceptual models. Because of limitations in their abstract thinking abilities, they need concrete models to understand both simple and complex ideas. For example, the motion and relative position of the Earth, Moon, and Sun produce eclipses that are better understood through the manipulation of a physical model. Likewise the action of the heart is better understood when compared to a pump, and the work of the digestive system is better understood when compared to a waste treatment plant. Computer simulations are useful conceptual models for furthering an understanding of complex scientific concepts.

As students mature and become more abstract thinkers, increased emphasis can be placed upon mathematical models. Before this time, understanding the mathematics that describes a falling body is not usually possible. Yet once abstract reasoning is feasible, then the richness of mathematics added to conceptual cognizance makes many aspects of science more meaningful.

Constancy and Change

Science and mathematics are often concerned with understanding, creating, and/or controlling change. Of course, change can vary widely from no change at all (we call this constancy), to almost infinite change. Other terms related to change and constancy are stability and equilibrium (terms that define a physical system when energy for action dissipates), conservation (when a quantity is reduced in one place, it is increased equivalently in another), and symmetry (which describes constancy of form). While these broad notions show up in all the sciences, stability, equilibrium, and conservation are most important to the physical sciences; conservation and symmetry are critical to the life sciences.

Some changes take place so slowly that they go almost unperceived by humans. Changes in the earth's crust, such as mountain building, fall into this category. Other changes, such as the relationship between the numbers of predators and prey, the recycling of matter in the ecosystem, or seasonal changes, are cyclical and need to be observed for extended periods of time in order to perceive the patterns of constancy and change. Still other changes take place so fast or occur in systems so small that people have come to use technology to make sense of them. Molecular biology and atomic physics include many examples of systems that cannot be studied directly.

The concepts of diversity, variation, adaptation, and natural selection relate directly to constancy and change. As the environment changes, natural selection chooses the expression of a variable trait which best enables the individual to adapt, survive, and reproduce. Gradually, over a long period of time, the species changes or evolves. When, a particular trait is observed for only a short time, however, then little or no change in the population may be observed. Thus, the population trait being observed appears to be stable or constant. A very different conclusion would be reached if the same trait were studied over a long time interval.

Measurement and Scale

Measurement quantifies observations of objects and phenomena, making comparisons more accurate. Size, volume, area, weight, mass, temperature, distance, velocity, and many other attributes can be directly measured in science labs, and classrooms, beyond the school walls; other attributes, such as evidence of the energy related to atomic particles, can be indirectly measured. Measurement is a critical theme and a crucial skill in science and operates throughout all the sciences. As students' sophistication increases with age and experience, so too does their ability to make more precise measurements and to use more refined and complex instruments for measurement.

Scale within our world varies so widely that it can easily boggle the mind. Estimating the number of stars in the universe or comprehending the size of a subatomic particle is difficult even for the most experienced scientist. To do so, we use mathematical representations that in themselves are difficult to understand. Scale includes not only the idea of ratios as well as upper and lower limits of variables, but also the notion that some "laws" of science operate only within a certain range. Students' understanding of measurement and scale increases as they have a variety of experiences with magnitudes and the effects of altering them and their cognitive development matures.[12]

Table 5 presents the understandings that Georgia's students should master relative to the "Vehicles for Understanding and Doing" discussed in this section. For a more complete discussion of the themes contained in this section, see chapter 11 of *Benchmarks for Scientific Literacy* (AAAS,1993), *Science For All Americans* (AAAS, 1990) and the emerging national science education standards. Also refer to measurement and scale in Table 2 in the mathematics section of this learning framework and the measurement standards in *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989).

TABLE 5 - Vehicles for Understanding and Doing

Level	Systems	Models	Constancy and Change	Measurement & Scale
Primary	Most objects are made of parts. All parts are needed for a system to work. A system can do things the parts can't do by themselves.	A model is different from the real thing but helps us learn about the real thing. Simple analogies help to explain how things work.	Things change or stay the same in many ways. There are many ways to change. Changes occur rapidly or slowly.	Objects vary in size, weight, age, speed, volume, etc.
Elementary	Parts influence the whole system. The system won't function correctly if a part doesn't. The arrangement of parts helps the system function in a certain way.	Changes in models should reflect changes in the real thing. Models come in many types - maps, geometric figures, number sequences, analogies, graph, sketches, diagrams. Models are useful tools for understanding a process or natural phenomenon.	Some features changes, others don't. Changes can be steady, repetitive, or irregular patterns. Graphs help explain and predict change.	Most objects have limits. Finding the upper and lower limits of an object or process helps understand the particular value. Properties such as speed, size, distance can be compared as fractions or multiples of each other. Different units of measurement are interrelated.
Middle Grades	Systems include both processes and components. Output from one part of a system can be input to another. All systems are connected to other systems. Feedback is a function of systems operating effectively.	Models are used to think about processes that happen too fast or slow, are too large or too small to view directly. Different models can represent the same real object. Models applications are improved through technology.	Physical and biological systems establish equilibrium with their surroundings. Cyclic changes follow predictable repetitive patterns over time. Graphs and equations help explain and predict change.	Properties of a system depending on volume change out of proportion to those depending on area. Summaries & averages become important in communicating about complex systems.
High	Systems have properties different from those of the parts. Systems operate within boundaries. Predicting how a system will react if one part is changed is difficult.	Mathematical models help to understand relationships. Technology improves models. Useful models predict behavior of objects and events successfully. Applying technology enhances models and understanding.	Equilibrium occurs when the rate of change is constant. Whole systems can remain constant while parts change. Matter & energy are dynamically interrelated. The relationship between energy is dynamic	In large and small numbers, powers of ten allow comparisons. As parts of a system increase in number, the number of interactions rapidly increase. All properties are not affected equally by change in property. Change in one property of a system does not equally affect its other properties.

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Science Big Ideas

The major science content understandings in this framework are based upon those discussed in *Benchmarks for Scientific Literacy* (AAAS, 1993) and the emerging national science education standards. Emphasis in this framework is placed distinctly on the big ideas and concepts of science. These are the major concepts of science that have the potential for lasting and meaningful effect on the world, or the physical and mental well-being of humanity. The details and facts, so often the primary emphasis of today's science teaching, must only be stressed to the degree that they shed light upon and help to further develop these big ideas. Based upon recommendations in the two sets of standards cited above, we have chosen to separate the content section of this framework into three broad categories -- the physical setting, the living world, and science and technology as a human endeavor. Details about these three areas follow.

The Physical Setting

The physical setting focuses on the structure of the universe and the major processes that shape it. Concepts related to the universe, the Earth, processes that shape the Earth, structure of matter, energy transformations, motion, and forces of nature are subsumed under this heading. Students will learn about aspects of the universe and our solar system and the processes that fashion these vast areas. They will learn about the Earth, its history, future potential, and especially about the processes that affect it, making it such a dynamic system. They will also study matter, learning characteristics of various particles, elements, and compounds and explore how various substances interrelate and interact. Energy concepts, including their many forms, their transformations, and their effects on the world, are another major ingredient about which students will learn. They will study moving bodies and the laws that govern their motion as well as the complex forces that act upon bodies. Science investigations of the physical world should take place in the classroom, laboratory, outdoor settings, and at resources such as museums, amusement parks, and industries which significantly utilize concepts as their foundation.

The Living World

The living world includes all aspects of our world that relate to life. These include diversity of life, the transfer of inheritable characteristics from one generation to another, the cellular structure of living organisms, the interdependence of all organisms and their environments, the flow of matter and energy in living systems, how living things change over time, and the human organism[13]. Elementary students begin their study with concrete experiences in their immediate "neighborhood." This includes plants and pets found at home and in the classroom. Gardening is a great entrance for elementary children into the wonders of the living world. Gardening also offers students an avenue to become aware of physical attributes such as soil and moisture and how they impact the living world. Plants, birds, insects, all become fascinating parts of a system into which young gardeners plant themselves!

Since middle-school students are entwined with their own changes and development, it makes sense to address human biology with them at this time. On the other hand, high school is the time for a look at the living world in greater detail. While viewing the role of oneself in the living world is essential from primary through the secondary science program, in the high school program particular emphasis is made on each individual's responsibility as a steward of the world. Understanding the interdependence of all organisms and viewing oneself as an essential contributor to the success of all living and physical aspects of the universe can only come with maturity in scientific understandings.

Science and Technology as a Human Endeavor

Science is often taught in a manner that conveys only the dry facts of what is known and how we know it. Yet, students of all ages are crying out for meaning and connections to their own world. This section of the "Big Ideas" of science focuses on making sense of science relative to today's world and to the place of humanity in that world. For example, understanding the religious and political influences that helped to keep Gregor Mendel's work "lost" during the late nineteenth century gives added meaning and context to his work. It also sheds light on the ways in which people affect science. This section of the framework makes connections between the history of science, the nature of science as inquiry, and the application of science and technology to the world today. It is necessary to understand how personal, social, economic, and political beliefs influence science and technology. Galileo was persecuted by religious leaders for promoting the Copernican theory of heliocentricity. The agricultural industry of the south was revolutionized by George Washington Carver following the demise of "cotton as king." Today questions related to genetic engineering, pesticides, and space exploration represent only a few of the topics that are intertwined in science and technology endeavors.

Science and technology as human endeavors can be viewed from the multiple perspectives of the designed world, the history and nature of science, as well as science, technology and society. The designed world is the result of human engineering solutions being applied to real-world problems and the human uses of technology in such areas as agriculture, manufacturing, energy resources and their use, health, technology, communication, and information processing *Benchmarks for Scientific Literacy*.[14] The history and nature of science examine the contribution of people to scientific understanding and stress scientific inquiry as a problem-solving technique occurring across time and cultures. The contribution to, and relationship with, the politics, economics, and values of society are examined in the section entitled science, technology, and society.

Elementary school students will learn that humans are the cause of environmental problems and, therefore, must develop the cure for these problems. Middle school students will learn that science influences and is influenced by the culture, economics, history, and politics of a society. High school students examine how the Earth's natural resources must be carefully managed and conserved if they are to be available for future generations.

Table 6 presents an overview of the goals students should achieve at each level en route to becoming scientifically literate. As in previous tables, goals are laid out by grade-level bands.

Table 6
Science Big Ideas - The Physical Setting

Level	The Universe	The Earth	Processes That Shape the Earth	Structure of Matter
Primary	The sky appears to be different at different times. The sun and moon change appearance and position over time.	Many natural changes have a repeating pattern (e.g. weather for a week, a month, or over years). Water can be a liquid vapor, or a solid & can change for one state to another.	The process of change occurs in a variety of situations. Living organisms can change their surroundings in many ways.	Objects are classified based on observable properties. Objects can change but not all objects or materials respond to change in the same way.
Elementary	The patterns of stars remain the same, but their locations change with the seasons. Tools such as binoculars, telescopes are used to observe celestial objects. Visible celestial objects such as stars, moons, and planets have specific properties. Motions of planets are complex yet predictable.	The Earth's gravity pulls objects toward the Earth's surface. The rotation of the earth produces the day-night cycle. Revolution of the earth around the sun produces an annual cycle. The water cycle includes evaporation & condensation. Air has all the characteristics of matter.	Wind, water, waves, ice can cause changes in the Earth's surface (erosion, transport, deposit). Soil is a combination of weathered rocks and organic matter. Rocks and minerals vary in their composition.	Heating and cooling changes objects in many ways. The weight of an object is the sum of the weight of its parts, Some parts of objects are too small to observe without magnification, New materials made from two or more substances have properties different from those of the original substances. Objects can be classified in ways such as weight, conductivity, buoyancy, magnetic properties, solubility, etc.

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Table 6
Science Big Ideas - The Physical Setting (cont'd)

Middle Grades	Planets in our solar system vary in size, composition, surface features, number of moons and distance from the Sun. Our Sun is on the edge of one galaxy and millions of galaxies make up the universe. Light from the Sun requires minutes to reach the earth while light from stars in other galaxies may take billions of years.	The Earth's position in space produces the daylight and the seasons. The orbit of the Moon around the Earth produces the phases of the Moon. The water cycle plays a role in weather, climatic patterns and availability of fresh water. Changes in atmosphere, in ocean content, or Earth's crust impact climate. Conservation and recycling prolong availability of Earth's resources.	Heat flow and movement within the Earth produce earthquakes, volcanic activity, and mountain formation. Rocks can change forms and are constantly being formed and worn away. Earth processes occurring today have happened for millions of years. The Earth has a long history of change documented in its rock record. Soil composition is determined by rock type and by action of living organisms (including humans), water, and air.	Description of matter in terms of atoms and molecules have changed as scientific investigations progressed. Density, melting, and boiling points are characteristic properties of matter. States of matter are described by atomic or molecular movement. Elements are classified by physical and chemical characteristics. Variables such as temperature and pH affect reaction rate.
High	Current theories of formation of the universe can supply scientific evidence to determine the age of the universe. Stars exhibit a characteristic life cycle. Technology and space exploration have added to our knowledge of the universe. Mathematical and computer models are useful to study evidence describing the universe. The investigations of Ptolemy, Copernicus, Kepler, and Galileo contributed to the heliocentric view of the solar system.	Life on Earth is adapted to the physical setting including the force of gravity, and amount of radiation, etc. Weather and climate involve energy transfer into and out of the atmosphere.	Photosynthesis affects the oxygen content of air . The rock cycle illustrates the conservation of matter in formation, weathering, sedimentation and reformation of rock. Evidence of continental drift provides the basis for the theory of plate tectonics as proposed by Alfred Wegener. Plate tectonics explains activity and earthquakes.	Atomic structure, radioactivity, and chemical bonding can be explained in terms of subatomic particles. Atomic configurations determine molecular properties, including arrangement patterns and reactions. Concentration of reactants, temperature, pressure, and presence of catalysts affect reaction rates. The Curies, Ernest Rutherford, Lise Meitner, Enrico Fermi have contributed to our understanding of radioactivity. Nuclear fission, fusion, and radioactivity play a role in the development of alternative energy sources, new medical applications, weapons of war, and scientific research.

Table 6
Science Big Ideas - The Physical Setting (cont'd)

Level	Energy Transformation	Motion	Forces of Nature
Primary	The sun has different effects on land, air, and water. The scientific inquiry method can be used to answer the question "What makes it go?" for a variety of objects.	Things move in a variety of patterns. A push or a pull causes changes in motion. Vibrating objects produce sound. Position and motion of objects is relative.	Gravity pulls objects toward the center of the Earth. Magnets attract some metal objects.
Elementary	Heat is produced in a variety of ways. Heat can be transferred or exchanged between objects in different ways. Objects can be classified based on their heat conductivity. Heat production and light are transferred. White light is composed of many colors of light.	Changes in speed or direction are affected by the size of force used and mass of the object. Different objects travel at very different speeds.	Some forces such as gravity and magnetism can act on an object from a distance. Electricity comes in two forms - static and current. Electrically charged objects can push or pull other objects.
Middle Grades	Energy cannot be created or destroyed, only transformed. A variety of biological, physical, and astronomical events involve energy and energy transformations. Heat is conducted by radiation, conduction, convection. Energy occurs in different forms, and can be transformed from one form to another.	Properties of light include propagation, reflection, and refraction. Light and sound waves are perceived by sense organs. The effects of unbalanced forces acting on an object can be measured as changes in position, direction, or speed. The basic properties of waves (e.g., sound, water, light, seismic) can be explored using physical models. Friction has an effect on motion.	The gravitational force exerted by one object on another depends on the mass of each object and the distance between them. The Sun's gravitational pull keeps the planets in the solar system in orbit. Changes in electric currents produce changes in magnetic fields and vice versa. Different materials respond differently to electric forces.

Table 6
Science Big Ideas - The Physical Setting (cont'd)

High	Heat energy and temperature depend on atomic or molecular motion. During an energy transformation, heat energy produced is often lost to the surroundings. Different amounts of potential energy are associated with different atomic and molecular configurations. An energy decrease in one place is accompanied by an energy increase in another. Energy transformation occurs at the atomic level, e.g., nuclear reactions, absorption or radiation of light. Einstein's relativity theory explains the relationship between matter and energy in nuclear reactions.	A change in motion of an object is proportional to the applied force and inversely proportional to the mass. When a force is exerted on an object, the object exerts an equal force in the opposite direction. Newton's Three Laws based on concepts of mass, force, and acceleration can be expressed as equations. All motion is relative to its frame of reference. The properties of waves explain many of the properties of light. The electromagnetic spectrum of waves is described in terms of wavelength and frequency.	The strength of a gravitational force is proportional to mass and distance. Electromagnetic forces within atoms hold atoms and molecules together and are involved in chemical reactions. Electrical charges can be positive or negative. Different materials respond differently to electric forces at varying temperatures. Interaction between magnetic forces and electrical forces are the basis for motors, generators, and technologies that produce electromagnetic waves. Forces holding an atom are responsible for nuclear reactions. Newton's unified view of force and motion and his mathematical analysis of gravitational force explain the motion of the orbits of planets. Einstein's theory of relativity has been used to make prediction about the behavior of atoms and astronomical bodies.

Table 6
Science Big Ideas - The Living World

Level	Diversity of Life	Heredity	Cells	Interdependence of Life
Primary	Some plants and animals can be very similar to each other while others can be very different. Plants and animals have characteristics which help them adapt to different environments.	Differences exist among similar individuals in a population. Offspring resemble their parents.	All living things have similar basic needs such as water, fooc and air. A hand lens to make things appear larger and easier to observe.	Living things can be found in a variety of habitats. Animals need other animals and plants for food and shelter.
Elementary	Living things can be observed and classified based on various observable features. A variety of classification systems exist. A hand lens and microscope are useful for observing the characteristics of organisms.	Some similarities are inherited while others are learned. A reliable way to transfer information from one generation to another must exist for offspring to resemble their parents. Observing life cycles of organisms help to understand populations.	Some organisms consist of one cell but carry on all basic life functions. Microscopes help us observe cells of an organism.	Some plants and animals in an environment thrive or survive better than others. Microorganisms can be beneficial to other organisms. Plants and animals interact at different levels with one another. Changes in habitat can effect living things.
Middle Grades	Plants and animals are different based on food/energy requirements. All living things are interconnected in two global food webs (one aquatic and one terrestrial). Plants and animals have body plans and internal structures which help them survive. External and internal features are used to classify living things. Some organisms can't be classified as plants or animals.	Organisms reproduce sexual and asexual. A fertilized egg contains genetic information from both parents and which multiplies to produce an organism with copies in each cell. Selective breeding produces plants or animals with desired traits. The work of Gregor Mendel was significant to the study of genetics.	Microscopes enable us to observe the details of cell structure. Different cells make up different body tissues and organs. Most cells have similar functions. Cells are organized into tissues, tissues into organs, organs into systems, systems into organisms.	Organisms with similar basic needs may compete with each other in an environment. Organisms develop relationships which can be mutually beneficial or competitive. Ecosystems contain biotic and abiotic factors.

Table 6
Science Big Ideas - The Living World (cont'd)

High	DNA sequences are used to show relationships between organisms. Variation within a species enhances survival of that species when changes in the environment occur.	Gene recombination produces variation in organisms. Genetic information is passed from parent to offspring through DNA molecules. Changes in DNA can alter the genes of an organism. Factors such as radiation and chemicals can cause gene mutations and be passed on to offspring. Multicellular organisms contain a variety of cells that have different functions based on which DNA is producing proteins in that cell. James Watson, Frances Crick, and Rosalind Franklin conducted research to determine DNA structure.	Cells are covered by membranes and have complex internal structures that perform life functions. The structure and function of protein molecules within cells are determined by their sequence of amino acids. DNA provides instructions for making protein molecules. Mutations result from changes in the DNA molecule. Certain chemicals or radiation can cause gene mutations. Variables such as temperature, pH, and the presence of catalysts can influence the functioning of a cell.	Ecosystems, although relatively stable over time, are influenced by environmental factors which can affect population size. Cyclic fluctuations based on a state of rough equilibrium occur within an ecosystem. Humans and human activity can alter the equilibrium in ecosystems.

Table 6
Science Big Ideas - The Living World

Level	Flow of Matter and Energy	Evolution of Life	The Human Organism
Primary	Both plants and animals need food and water, but plants need light to make food while animals must take in food. Materials can be recycled and used again, often in different forms, as in recycling plastics.	Different plants and animals have unique features that help them survive in different places. Some plants and animals in the past have become extinct, while others were like those living today.	All humans are alike in many ways, yet each is unique. Humans use their senses to observe and make sense of the world around them. There are many things people can do to stay healthy.
Elementary	Food for all animals can be traced back to plants. Living organisms need some source for energy to live and grow. When living organisms die and decay, matter is recycled to produce new organisms.	Individuals of the same kind vary slightly, giving some advantages for survival. Fossils can be compared to present day organisms and each other by observing similarities and differences.	Humans change physically and cognitively as they mature. The human body is composed of systems, (e.g., circulatory, respiratory). Certain substances (e.g., meats, dairy products) contribute to growth and repair, while other substances (e.g., tobacco, drugs) contribute to body damage. The human body can defend itself against certain diseases. Vaccines can be used to protect the body against certain diseases.
Middle Grades	Food provides fuel and building materials for all organisms. Sunlight is the source of energy for most food production. Through food webs, energy and matter are transferred from one organism to another. Energy and matter can be transformed as they are transferred from one organism to another.	Selective breeding can produce organisms with characteristics different from previous generations. Changes in environmental conditions can affect the survival of both individuals and entire species. The fossil record found in sedimentary rock provides evidence for the long history of changing life forms.	The human body is similar in structure and function to the bodies of many other animals. Humans exhibit behavioral patterns similar to those exhibited by other animals. Human development, like that of other animals, proceeds from fertilization to birth, to adulthood, to old age. The human body is composed of organs functioning together. Humans can control and change the environment to stay healthy and defend against disease.

Table 6
Science Big Ideas - The Living World (cont'd)

High	The burning of fossil fuels releases stored energy and impacts the C-O cycle. The availability of energy, water, oxygen, minerals, and the availability of ecosystems to recycle matter affect the amount of life any environment can support. The chemical elements in the molecules found in living things pass through food webs, combining and recombining in different ways. Photosynthesis stores light energy as chemical energy, and cellular respiration releases that energy for use by living organisms.	Molecular evidence supports the idea that today's species developed earlier species. Natural selection provides the mechanism for choosing which new gene combinations and mutations result in viability as the environment changes. Heritable characteristics which can be observed at both the molecular organismal level influence how an organism will survive and reproduce. As explored by Charles Darwin, natural selection provided a scientific explanation for the changing life forms on earth.	The development of the human body is directed by unique human DNA, produces human anatomy. The functioning of the human body systems involves the interaction of molecules. Human behavior is the result of heredity and experience. Human health is affected by heredity, the body's immune response, and technology.

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Table 6
Science Big Ideas - Science and Technology as a Human Endeavor

Level	History & Nature of Science	Science Technology and Society	The Designed World
Primary	Children's questions about science phenomena can be answered by scientific investigations.	Humans have needs (e.g. food and water) required for survival and wants or desires which make life better. Pollution is a product of human activity and humans must devise strategies to solve pollution problems.	Technology affects the growth and distribution of food for humans. Materials are selected for specific properties and tools are used to make work easier. Information can be sent and received by various methods, each having advantages and disadvantages. Technologies can be used to storage and retrieval of information. Vaccines and medicines can be used to prevent and treat disease.
Elementary	Student's "if...then" and "what if" questions can be answered by scientific inquiry. Reading and discussing stories about scientists help children to understand the nature of science.	Resources include material resources which can be measured (e.g., oil, coal) and non-material resources (e.g., beauty, safety) which can't be measured easily. Humans are the cause of environmental problems and, therefore, must develop the cure for these problems.	Technology impacts the variety and quality of the world's food supply. Natural materials are changed during processing. Resources can be managed to reduce waste. Information and communication technologies have common characteristics and problems. Body measurements (e.g. temperature, heart rate, blood chemistry) provide clues to human health and aid in diagnosis of illness.
Middle Grades	The nature of a scientific investigation is determined by the question asked. Scientific knowledge is advanced by communication, collaboration, and honesty among members of the scientific community. The existing science culture has been developed by scientist over many years.	Science influences and is influenced by culture, economics, history and politics of a society.	Technologies hold promise to enhance the living world but it also poses problems. Manufacturing involves a step by step process that impacts society and is impacted by society. Information can be transmitted in a large variety of ways, each with its own set of problems. Technology can be used as a tool for solving problems and managing information. Technology has impacted human health by improving sanitation methods, diagnostic procedures, and synthetic drugs and hormones.

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Table 6

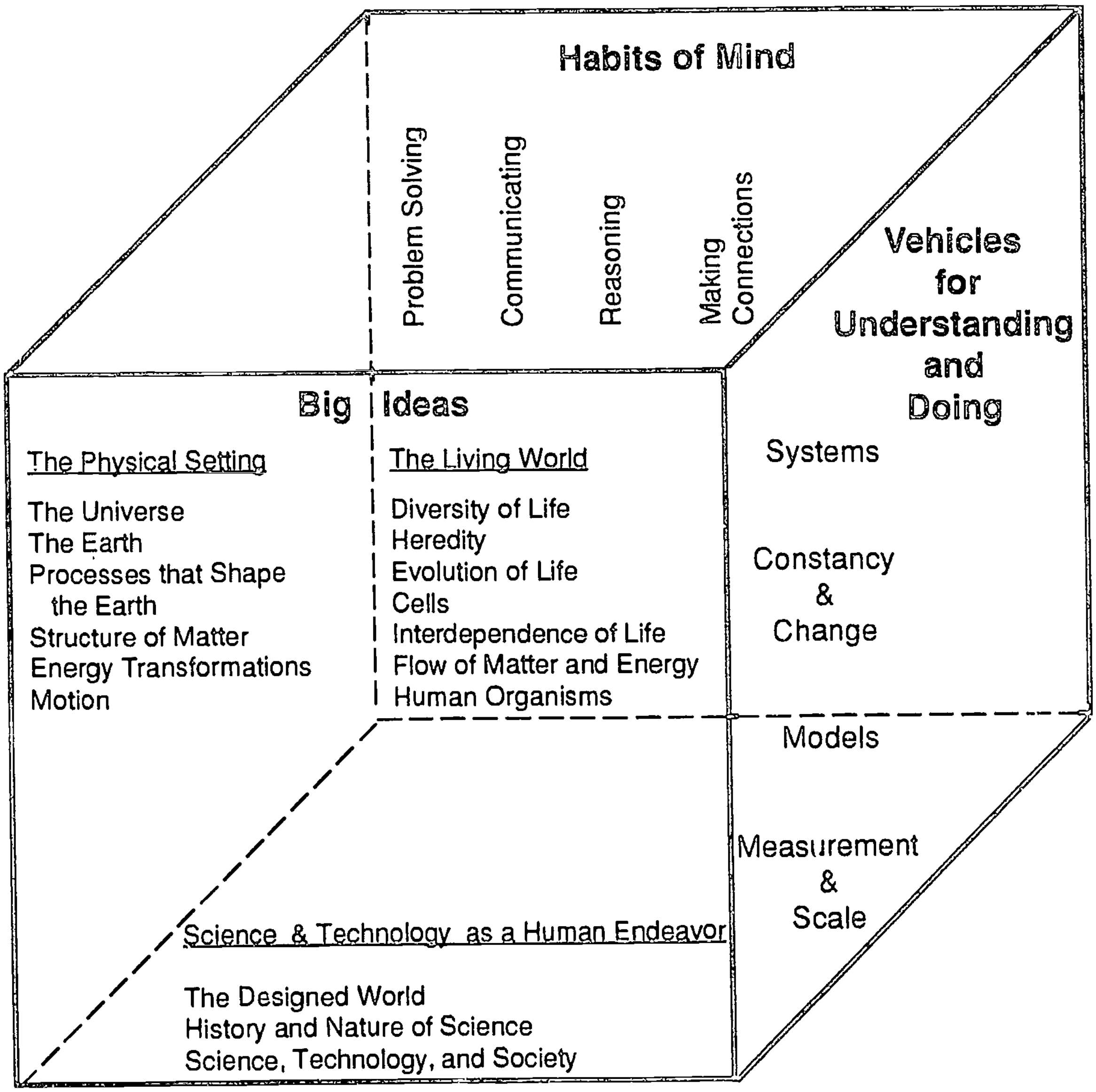
Science Big Ideas - Science Technology as a Human Endeavor

High	Everyday problems can be solved by using methods of scientific inquiry. Scientific explanations result from inductive or deductive reasoning. Additional evidence results in alteration of scientific explanations.	Population growth is affected by the availability of needed resources such as food, water, and living space. The Earth's natural resources must be carefully managed and conserved if they are to be available for future generations. Natural and human activities, including political, economic, and cultural, impact the environment. Science and technology hold promise to meet society's challenges.	Genetic engineering impacts agricultural economy and the overall ecosystem. Research and subsequent by-products of manufacturing impact society. Consequences of dependence of society on communication methods that are transmitted and received using electrical, sound and heat energy should be evaluated. Technology can be used to develop models that explain scientific phenomena and to make decisions. Biotechnology will be useful for future generations.

Putting It All Together

The Capacity Cube (C^3) illustrates how "Habits of Mind, Vehicles for Understanding and Doing, and the Science "Big Ideas" intersect and interrelate at all levels of schooling in Georgia. This three-dimensional graphic represents the belief that science, at its core, is not a one-dimensional enterprise. Rather, it is the full integration of thinking abilities, scientific values, and broad themes that cut across all disciplines and the concepts that make up what most people think of as science.

Elements of Teaching and Learning



Part III

Engaging Each Student in Productive Learning

We live in a world full of mathematics and science. From the stone in Atlanta's MARTA tunnels to the geometry and engineering feats that rise above them; from the sand dollars on the beach at Jekyll Island to the trout in the mountain streams; from the census count in Albany to the probability of winning the lottery--all of us use and benefit from the world of phenomena and numbers in which we live.

There are many topics in mathematics and science that naturally attract students. They are interested in tornadoes, stream creatures, their own bodies, how amusement park rides work, sports statistics, and the making and spending of money. These or similar interests should be used as the gateways to entice students to a deeper understanding, use, and appreciation of their world.

More important to the future of Georgia and Georgia's students is the fact that interesting topics and engaging instruction opens the door to mathematics and science for all students. Research tells us that most of the students who are successful in participating in mathematics and science have traditionally been white males. If our students are to grow up, with rewarding careers that enrich their lives psychologically, and economically, we will need a technologically competent work force. Participation rates of female and minority students must increase. For these rates to increase, we need to make all students feel that they are welcome and can be successful participants in the technological world. For these rates to increase, we must include all children in the high expectation for success and bring into reality the belief that all children can learn science and mathematics.

Middle-grades years are critical to the formation of attitudes about oneself in relation to science and mathematics. These attitudes are critically influenced by how science and mathematics are taught. "Therefore, it is the responsibility of all members of the learning community to enter into a covenant which demonstrates in attitude and behavior the belief that each individual is valued and respected" (GIMS Diversity Framework, 8/4/94 Draft, p. 1). The purpose of this section is to describe a learning environment that enriches each individual through the relevancy and usefulness of science and mathematics.

How Should Science and Mathematics Be Taught?

How science and mathematics should be taught is much more than a question about what a teacher should be doing in class. What students learn is fundamentally connected with how they learn.[15] According to the Curriculum and Evaluation Standards for School Mathematics of the National Council of Teachers of Mathematics (1989), "Serious mathematical thinking takes time as well as intellectual courage. A learning environment that supports problem solving must allow students time to puzzle, to be stuck, to try alternatives and to confer with one another.... Students' learning of mathematics is enhanced in a learning environment that is built as a community of people collaborating to make sense of mathematical ideas."[16]

All of the recent national efforts to redefine priorities in science and mathematics education have common elements. They reflect similar views on how individuals learn. They focus on what happens in effective classrooms and what makes these classrooms effective. In order to describe settings that enable people to learn, the **Learning Framework** will first describe how students learn, and then focus on four aspects of teaching:

- the kinds of tasks in which students are engaged
- the kinds of discourse present in classrooms
- the environment for learning
- the analysis of instruction--keeping track of progress in achieving mathematical and scientific literacy[17]

How Do People Learn New Ideas?

Students come to school with lots of experiences with, ideas about, and explanations of the natural world. The scope of these ideas are as diverse as the students' backgrounds and they are often different from those of scientists and mathematicians. For example, most sixth graders believe that a heavy metal ball will fall to the ground faster than a light wooden one of the same size.

These ideas have grown over a long period of time, supported by observations that paper (light) falls more slowly than a rock (heavy). They are however, contradictory to the scientific observations about falling objects. Students will have to become dissatisfied with their old idea and abandon it before they can really learn the new idea that gravity accelerates all objects at the same rate and that their experience with the rock and paper demonstrates something else. Students can't learn by adding new information to old misconceptions. They have to change their conceptions.

While the process varies from individual to individual, changing a conception involves a series of steps:

1) Students become dissatisfied with their existing conception. Therefore, teachers must know what likely misconceptions are, and create an environment where the students become aware of the misconceptions and have a need for new ones. In this environment, students must consider

and talk about what they think, and teachers must listen in order to hear the student conceptions.

2) Students achieve a minimal understanding of the new scientific or mathematical conception.

3) The new conception appears plausible to students.

4) Students see the new conception as fruitful and useful to understanding in a variety of settings.

Individuals who promote a constructivist perspective believe that each learner creates his/her unique understanding. Constructivism assumes that individuals are creative and dynamic. Instead of merely being acted on by their situations, people act dynamically to effect changes based on how they think and regulate their activities.

Teaching procedures that illustrate constructivism were highlighted by Yager (1991):[18]

Seeking out and using student questions and ideas to guide lessons and whole instructional units;

Accepting and encouraging student initiation of ideas;

Promoting student leadership, collaboration, location of information, and taking actions as a result of the learning process;

Using student thinking, experiences, and interests to drive lessons (this means frequently altering teachers' plans);

Encouraging the use of alternative sources for information both from written materials and experts;

Using open-ended questions and encouraging students to elaborate on their questions and their responses;

Encouraging students to suggest causes for events and situations, and encouraging them to predict consequences;

Encouraging students to test their own ideas, i.e., answering their questions, their guesses as to causes, and their predictions of certain consequences;

Seeking out student ideas before presenting teacher ideas or before studying ideas from textbooks or other sources;

Encouraging students to challenge each other's conceptualizations and ideas;

Using cooperative learning strategies that emphasize collaboration, respect individuality, and use division of labor tactics;

Encouraging adequate time for reflection and analysis; respecting and using all ideas that students generate; and

Encouraging self-analysis, collection of real evidence to support ideas, and reformulation of ideas in light of new experiences and evidence. (pp. 55-56)

This view of learning affects what happens in teaching. It also affects the process by which adults change their conceptions and it helps us understand why change is so difficult.

Building the Capacity Cube

Imagine trying to build a three-dimensional figure like the capacity cube (see *The Nature of Mathematics* and *The Nature of Science*). Consider any of the three dimensions of the "Habits of Mind" or the "Vehicles for Understanding and Doing" or the "Big Ideas" -- along with their connections. It quickly becomes apparent that there are concepts and skills that are prerequisite to other concepts and skills, and some concepts and skills simply have to wait until children are ready for them. In building the capacity cube as in constructing any three-dimensional structure, there are choices about whether to concentrate on length, width, or height. That is, as you focus in on a "big idea" from science or mathematics and how and where that big idea relates to the "habits of mind" and "vehicles for understanding and doing" will affect other choices that might follow.

What Instructional Model Can Be Used to Achieve Conceptual Change?

The American Association for the Advancement of Science suggests that teaching should be based on learning principles that are derived "from systematic research and from well-tested craft experience." [19] In keeping with the character and spirit of inquiry and scientific and mathematical values, teaching should begin with questions dealing with phenomena, not answers to be memorized or learned. Students should engage in the use of hypotheses and the collection and use of evidence. The instructional activities in the classroom should include designing investigations, using the processes of science and mathematics, and engaging in hands-on experiences. Creativity and curiosity should be encouraged and highly regarded, and the students should work together as a team whenever possible.

The National Council of Teachers of Mathematics identifies as the central goal of the *Curriculum and Evaluation Standards for School Mathematics*[20] the development of mathematical **power** for all students.

> "Mathematical power includes the ability to explore, conjecture and reason logically; to solve nonroutine problems; to communicate about and through mathematics; and to connect ideas within mathematics and between mathematics and other intellectual activity. Mathematical power also involves the development of personal self-confidence and a disposition to seek, evaluate and use quantitative and spatial information in solving problems and in making decisions. Students' flexibility, perseverance, interest, curiosity, and inventiveness also affect the realization of mathematical power."[21]

NCTM also identified needed changes:

- toward classrooms as mathematical communities--away from classrooms as simply a collection of individuals
- toward logic and mathematical evidence as verification--away from the teacher as the sole authority for right answers
- toward mathematical reasoning--away from merely memorizing procedures
- toward conjecturing, inventing and problem solving--away from an emphasis on mechanistic answer-finding
- toward connecting mathematics, its ideas, and its applications--away from treating mathematics as a body of isolated concepts and procedures[22]

While not prescribing an instructional model, these goals certainly point toward certain tasks, discourse, and school environments required to approach the standards.

The National Middle School Association's task force on curriculum supports learning experiences that:

- help young adolescents make sense of themselves and the world about them
- are genuinely responsive to students' intellectual, physical, social, emotional, and moral development
- are highly integrated, so that students see the connectedness of life

- address students' own questions and focus upon enduring issues and ideas
- open doors to new ideas, evoking curiosity, exploration, and at times awe and wonder
- teach the full range of communication skills in functional contexts
- actively engage students in solving problems and a variety of experiential learning opportunities

At the same time, the following conditions are *counterproductive* and should be deemphasized in middle grades:

- a curriculum that consists chiefly of separate subjects and skills taught in isolation
- a faculty that is organized in departments
- exploratory courses isolated from academic endeavors and viewed as less important
- judgment of learning by the content in isolation from the process by which it is learned
- instruction dominated by textbooks and worksheets
- lecturing, rote learning and drill
- the tendency to label and track students into rigid ability groups[23]

The call for reform comes from all the professional societies. While couched in different terms and prepared by different individuals, there is widespread agreement about the kinds of reform that will probably be necessary. The next section presents an overview of areas of reform including "Teaching Tasks, Discourse, and Teaching Environments." This is followed by a discussion of issues surrounding documentation of student learning entitled "Keeping Track."

Teaching Tasks

In simplest terms, tasks are what students **do** in classrooms every day when they come to school. Tasks are the vehicles by which standards are achieved.

The NCTM Professional Teaching Standards for Mathematics define *tasks* this way:

> The mathematics tasks in which students engage--projects, problems, constructions, applications, exercises, and so on--and the materials with which they work frame and focus students' opportunities for learning mathematics in school. Tasks provide the stimulus for students to think about particular concepts and procedures, their connections with other mathematical ideas and their applications to real world contexts. Good tasks can help students to develop skills in the context of their usefulness. Tasks also convey messages about what mathematics is and what doing mathematics entails. Tasks that require students to reason and to communicate mathematically are more likely to promote their ability to solve problems and to make connections. Such tasks can illuminate mathematics as an intriguing and worthwhile domain of inquiry. A central responsibility of teachers is to select and develop worthwhile tasks and materials that create opportunities for students to develop these kinds of mathematical understandings, competence, interests and dispositions.[24]

If the word *science* were substituted for the word *mathematics*, science teachers would agree that the previous paragraph describes their most important responsibilities. The first two science teaching standards speak directly to the teacher's role in task identification, creation, and execution. In addition, the emerging science teaching standards support *inquiry*, which is defined in three ways that are consistent with a classroom filled with worthwhile instructional tasks:

1. the diverse ways in which scientists study the natural world seeking to develop explanations and the capacity to predict its behavior

2. the activities of students in which they develop understanding of scientific ideas as well as understanding of how scientists study the natural world

3. a manner of teaching that enables students to conduct scientific inquiry

Task-oriented teaching is more than activity. Good tasks are defined as ones that "do not separate...thinking from...concepts or skills, that capture students' curiosity and that invite them to speculate and pursue their hunches. Many such tasks can be approached in more than one interesting and legitimate way; some have more than one reasonable solution." [25] Tasks selected should be evaluated on their ability to accurately sample important concepts and processes of science and mathematics and to provide opportunities to practice skills in context. They have to be suitable for the students. The tasks should be based on what the students know and can do, what they are or can be interested in, what they need to work on, and how they are challenged.

Good classrooms are not ones in which the primary activity is the teacher transmitting information that the children are listen to, practice, and repeat.

> "The traditional approach to curricula, which is still dominant in most schools, assumed students came to school with the same experiences, progressed at the same rate and learned in the same way. Built to standards of efficiency, lessons were simple, standardized and easy to manage. The movement of the 1960s and 1970s was toward small, isolated behavioral objectives that stated what children will be able to do; this encouraged activities designed around those specific behaviors and separate testing of the objectives to see if they had been learned. This view of the curriculum fit common notions of how to educate large numbers of children efficiently."[26]

The desire to efficiently cover the material led to having curriculum emphasize basic skills and facts. Consequently the curriculum tended toward being repetitive and decontextualized and offering little integration of skills.[27]

While assessment will be discussed later, it is important to note now that as teaching becomes multidimensional in nature, so must assessment. Assessment is systematic evaluation of the evidence (or documentation) of thinking and doing (see Keeping Track). Assessment is central to instruction. Assessment must be a part of instruction.

Discourse

The NCTM Curriculum Standards use the term *discourse* to describe the interchanges that occur. "Like a piece of music, the classroom discourse has themes that pull together to create a whole that has meaning. The teacher has a central role in orchestrating the oral and written discourse in ways that contribute to students' understanding...."[28] Emphasis on active dialogue transforms classrooms from teacher-untried environments to student-centered environment.

Science teachers organized students into groups for laboratory work before the relationship between classroom setting and learning became a serious consideration. Laboratory (or experiential) activities in both mathematics and science actually lend themselves quite naturally to group work. The techniques used in the laboratory are also applicable to classroom situations. For instance, in a group problem-solving situation there might be a logical division of labor with students assuming differentiated roles or sharing responsibilities. Considerable research has documented the effectiveness of group work. (See Slavin and Johnson and Johnson.)[29] We have learned from business and industry as well as from education that in effective groups, every group member must contribute. We have also learned that as the diversity among the group members increases, so too, does the elaborative thinking and the give and take in explanations. Within heterogeneous groups a greater perspective seems to occur in the discussions which increase the depth of understanding, the quality of reasoning, and the accuracy of long-term reasoning.

Group activities have other advantages in a classroom. Because students construct their own understanding in different ways, it is beneficial to provide all students with different kinds of learning experiences. The particular contribution to learning that small-group work brings is the enhanced potential for students to clarify, debate, defend, elaborate, and evaluate with one another. "The negotiation and consensus building that are possible in... groups suggest that teachers should give serious consideration to employing (such) learning strategies when they consider it appropriate."[30]

Involving students in real-life situations is important. Real-life problem situations are important; they set the stage for teachers and students to interact about meaningful mathematics and science.

Teaching Environments

A primary goal of science and mathematics education is the development of students who believe in their ability to be successful scientific and mathematical thinkers, and the environment in which that education occurs is vitally important. **Central to that environment is an atmosphere in which students and student ideas are respected and valued.** Achieving that environment is the responsibility of the classroom teacher and the school system.

While philosophically there may be a commitment to equity-based science and mathematical literacy for all, recent history suggests that gender equity and equity for minorities and the disabled citizens in American mathematics and science education has not been the case in practice.

> "Women and non-Asian minorities are underrepresented in the science, mathematics and technology work force. Although women's share of the professional work force had risen to 40 percent in 1986, they still constituted only 15 percent of the employed scientists, mathematicians and engineers. In the same year blacks (who constitute 10

percent of all employed workers and 7 percent of the professional workers) and Hispanics (5 percent of all employed workers and 3 percent of professionals) each represented about 2 percent of the scientific work force. The physically disabled represented approximately 2 percent of scientists and engineers." [31]

Oakes identified three critical factors contributing to the inequality of participation in science-mathematics; and technology-related careers:

1. the lack of opportunities for women and minorities to learn science, mathematics, and technology

2. the low achievement of these groups in these subjects

3. the decisions made by members of these subgroups not to pursue science, mathematics, or technology as a career

Equity and Excellence: Compatible Goals (Malcom), the title of a 1984 report by the American Association for the Advancement of Science, summarizes the characteristics shared by high-quality programs that are designed to encourage participation in sciences by underrepresented groups. This report was reinforced by Investing in Human Potential (Matayas & Malcom, 1991.) Quality programs share the following characteristics:

1. strong academic components in science, mathematics, and communication, that focus on enrichment, rather than remediation

2. applications and career emphasis

3. integrative approaches

4. involved community resources

5. opportunities for in-school and out-of-school learning

6. involved parents and other significant adults in their students' learning and goal-setting process

7. support systems for the achievement of high academic and personal goals. [32]

It is important to note that the techniques and characteristics described for quality programs are the same as those necessary for students to construct their own knowledge. The idea that an environment that nurtures and supports minority students is beneficial for all students finds support in a curriculum-development project at the Lawrence Hall of Science in the 1980s.

One of the most important ways to achieve excellence and equity is through hands-on experiences. This notion is supported by research that suggests that the perceived deficits in logical thinking, visual-spatial tasks, mathematics, and mechanical tasks of low-achieving groups are due to differences in developed interests and past experience rather than inherent ability. Teachers must remember to make instruction relate to all students.

Simply "doing activities" does not in itself produce learning. Hands-on activities that are not accompanied by minds-on activities may be interesting, but fail to help students construct meaningful understanding.

> "All hands-on activities involve materials. The student learns by doing, using everyday materials such as plants, batteries and bulbs, or water, specially designed materials such as attribute blocks or algebra tiles, or instruments such as microscopes or meter sticks. But instructional materials must be sequenced to facilitate the students' construction of meaning. Giving students sets of activities without connections drawn among them leads to isolated bits of knowledge or skills that do not promote understanding but rather the forming of naive conceptions. The 'minds-on' part of instruction comes with dialogue, discussion and exploration using the hands-on materials." [33]

Technology is part of the physical and instructional setting. Technology provides important tools for learning. Technology may be as simple as simple as games or calculators that assist in concept development. Technology may be as complex as CD ROM, distance learning, and multi-site telecommunications.

Technology transforms the classroom. Through video tours and electronic field trips, the world comes to the classroom. Through technology, students do not have to be flown to an erupting volcano and risk injury from molten lava; issues such as access, safety, and cost become non-issues. Technology brings to the classroom experiences that were heretofore previously unavailable to all students. Decisions about when, how, and why to use technology are important. Technology is a tool and not an end, in and of itself.

Teachers need support and encouragement in the implementation of the vision as they transform science and mathematics learning opportunities for all Georgia children. The preparation of today's youth for tomorrow's world requires systemic change. The schools, communities, business, and industry and families must join together with students' families to ensure success for all Georgia children.

Keeping Track

To cause learners to "think and do" what scientists and mathematicians think and do is to provide all students with the power of theory, logic, and application to make sense of the world of today and the world of tomorrow. To cause learners to "think and do" in a systematic manner so that the evidence or documentation of that "thinking and doing" can be evaluated systematically is **assessment**.

Within the Learning Framework, the "thinking and doing" in mathematics and science that define the academic expectations for all students are the Habits of Mind, the Vehicles for Understanding and Doing, and the Big Ideas. These three dimensions represent the multidimensional nature of thinking and doing in science and in mathematics. The intersections of these dimensions represent the products of intellectual work. These intersections then become opportunities for students to demonstrate progress. Together, multiple opportunities for demonstrating progress at the individual student level become systems for teachers to keep track of the individual student's increasing sophistication in the theory, logic, and application of science and mathematics.

The character of the opportunities for demonstrating Habits of Mind, Vehicles for Understanding and Doing, and Big Ideas must be constructivist in nature. Just as students have multiple and different ways of coming to know, so too do they have multiple ways of demonstrating what they know. Thus, these opportunities must model the constructivist philosophy that undergirds the Georgia **Learning Framework**.

In order to support the learning and rigorous development of students, teachers must be good managers of people, resources, and time. As managers, teachers need clear, timely, and unambiguous evidence upon which to base decisions. The process of collecting this clear, timely, and unambiguous evidence is referred to within the **Learning Framework** as a process of documentation. And, just as the **Learning Framework** recognizes that there are multiple ways of knowing and multiple ways of teaching, so too must there be multiple ways of documenting what is learned.

In order for information about students' intellectual work in science and mathematics to be useful, meaningful, and credible, it must:

- be consistent with and reflective of teaching and learning in these disciplines
- yield timely information that is respected by students and teachers
- enable multiple users of the information to make comparable interpretations of the intellectual work

- provide comparable and consistent evidence of intellectual work over time

These opportunities for students to demonstrate periodically their Habits of Mind, Vehicles for Understanding and Doing, and Big Ideas can represent assessment opportunities if the opportunities themselves are positioned appropriately. It is important to remember that assessments are useful because they capture representative samples of student behavior in a systematic way. With respect to the **Learning Framework**, assessments have an important role in documenting evidence of the intellectual work that students produce in mathematics and science.

Samples of each student's intellectual work have value because they are collected in comparable or systematic ways. This feature ensures that all students have equivalent opportunities to demonstrate their "thinking and doing" in mathematics and science.

The second necessary feature is an extension of the systematic conduct of the assessment opportunity; that is the *systematic judging of student work*, or *scoring*. Again, the systematic nature of the judging of student work ensures equity and fairness.

As learning in science and mathematics follows the intersections of Habits of Mind, Vehicles for Understanding and Doing, and Big Ideas, there will be assessment opportunities that can be summarized (scored) by comparing the intellectual work with unambiguous and well-accepted standards. The student work itself must vary in complexity, amount of effort required, format of evidence, and importance just as the underlying instruction will vary in these same dimensions over the course of a year's instruction in science or mathematics. But when taken as a whole, the accumulated evidence or documentation of students' intellectual work becomes a vivid image of each student's habits of mind, vehicles for understanding and doing, and big ideas internalized.

These two features, systematic implementation and systematic scoring, distinguish assessment opportunities from instructional activities. Because assessment opportunities are expected to provide credible evidence of learning, assessment opportunities must have expressed safeguards for equity and fairness.

Equity and fairness take on very specific attributes in discussions of accountability assessment. Empirical evidence from assessments can be used to examine issues of adverse impact for specific populations. Likewise, item data from diverse populations can be used to remove items from assessments that evoke qualitatively different performance from different population groups while holding overall performance constant. These attributes require large databases and are typically inappropriate for analysis of classroom assessments.

However, the limits of our analytical techniques do not excuse us from addressing the importance of fairness and equity for classroom assessments as well. In fact, the issue is just as important and in many ways perhaps more important because assessments occur in the classroom much more often than accountability assessments occur, and thus, they have a much greater potential to negatively impact students' and teachers' perceptions and conduct.

One approach to addressing the issue of fairness and equity in classroom assessment is to broaden the focus of the assessment as well as the response mode possibilities of each assessment opportunity. This move to accommodate the multiple ways of knowing that undergirds the constructivist philosophy is in keeping with fairness and equity, if all students are provided the same flexibility and options within and throughout their instructional experiences.

Assessment in mathematics and science has received much attention in recent years due to an emphasis on accountability and the often poor match observed between what mathematics and science teachers want to teach and how they want to teach it and the structure and content of traditional assessment tools.[34] It is this correspondence between what science and mathematics learning should be and what assessment should be that must govern the character and quality of the documentation opportunities for every student. In this regard, the models for teaching and learning in mathematics and science must govern the definition and selection of assessment opportunities. There should be no, one and only one, right way to document what students think and do. There must be as many different ways of documenting knowing as there are ways of knowing.

The benefits of a constructivist philosophy for teaching, learning, and assessment cannot be overstated. A teacher who is able to assess students' knowledge, skills, and dispositions in a variety of ways can better understand what students know, what they do not know, and the strategies employed during mathematical and scientific tasks of various levels of complexity. A student who has a variety of ways to demonstrate knowledge, skills, and dispositions can build upon personal strengths while enhancing areas of potential strength.

Assessment should provide teachers and students with periodic and systematic snapshots of how students organize their science and mathematical knowledge as well as information about students' progress and motivation. Assessment should reflect the values of mathematics and science education. What is documented must be what is important, not just what is easy. "If students are to investigate, explore, and discover, assessment must not measure just mimicry in mathematics and/or science. By confusing means and ends, by making testing more important than learning, present practice holds today's students hostage to yesterday's mistakes." [35]

The repertoire of skills that undergird mathematical and scientific power include not only some traditional skills, but also many more powerful capabilities. For example, all students must be able to:

- Make decisions based on the collection, representation, and interpretation of real data
- Use tables, graphs, spreadsheets, and statistical techniques to organize, interpret, and present numerical information
- Judge the validity of mathematical, scientific, and technical information presented by the media and others
- Use scientific process skills as a reasoning tool
- Perform mental calculations and estimations with proficiency

The role of assessment is to serve learning and teaching by being grounded in views of what knowledge, skills, and dispositions all students will need for future success. Multiple forms of evidence are needed to support an educational environment in which all students will think and do as scientists and mathematicians think and do.

The new assessment paradigm, which speaks to the need for diversity in assessment opportunities, acknowledges that there is not likely to be one system or one process, that works to produce students who can think, have scientific habits of mind, and be mentally fit. In fact, the more that is known about instruction, learning behavior, learning style, and intelligence, the less reasonable it is to impose a single process for learning on students. Likewise, it is presumptuous to impose a process for assessment on students that does not recognize individuality. It is this somewhat radical paradigm shift[36] that opens the door to innovative assessment in the service of education.

With this paradigm shift, the following changes are likely to occur:

Decreased Attention Traditional Paradigm	**Increased Attention** Reform Paradigm
Teacher-Centered Instruction	Student-Led
Segmented School Schedule	Flexible Schedule
Rigid Curriculum	Flexible Curriculum
Separations of Content Domains	Thematic Instruction
Traditional Assessments	Performance-based Assessments

In assessment, there is emerging a continuum from traditional, multiple-choice tests to open-ended, free-response tests. At each end of the continuum and at the infinite number of points along that continuum can be types of opportunities whereby students demonstrate that they can "think and do" what scientists and mathematicians "think and do."

Another way to describe the assessment paradigm shift is to define the shifting elements:

Traditional Assessments	Performance-based Assessments
Controlled Time for Administration	Variable Time for Administration
Individual Effort	Individual Effort and/or Collaborative Effort
Controlled by Developer/ Administrator	Controlled by Students Administrator
Emphasis on Answer/Product	Emphasis on Process and Product
Focused and Discrete Content	Broad and Holistic Content
One Correct Answer	Multiple "Correct" Answers
Fixed Response Mode	Response Mode Selected by the Student
Performance Standards Empirically Derived	Performance Standards Derived from an Understanding of the Content

Given the discussion of the "Habits of Mind", "Vehicles for Understanding and Doing," and "Big Ideas" expressed in both the discussion of mathematics learning and science learning, it is likely that assessment opportunities will become more and more complex. It is likely that assessments that focus on discrete knowledge and skills will become less and less valuable to students and to teachers because they are less likely to describe the essence of our vision for all Georgia students to think and do what scientists and mathematicians think and do.

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Georgia Initiative In Mathematics And Science

Dear Friend and Colleague,

As a leader in mathematics or science education your assistance is being sought by the Georgia Initiative in Mathematics and Science (GIMS). Enclosed is a review draft of the **Georgia Framework for Learning Mathematics and Science**. Along with the review draft is a letter from Dr. Mike Padilla, Principal Investigator of GIMS, an explanation of a framework, a list of Georgians involved in the development of the review draft of the **Learning Framework**, and a copy of the review form. Also included in this packet is a description of the Learning and Teaching Portfolio. The **Learning Framework** is the first entry of the Learning and Teaching Portfolio which will include samples of exemplary practices in Georgia schools that will serve to amplify the **Learning Framework.**

The **Learning Framework** draft has been sent to over 1800 Georgians for review during the months of January and February. Following this period, a Review Committee will consider all the responses and recommend revisions to the framework. The revised document will be presented to the Georgia Board of Education in spring 1995.

We are seeking input to the review draft of the **Learning Framework** from all who care about mathematics and science education--from individuals and groups, from teachers and administrators, from parents and students, from community members, and from business and industry. It is for this reason that I am writing to you. As a leader in educational reform, your reaction to the review draft of the **Learning Framework** is important to us. We know that you have studied the national curriculum and assessment standards and have worked at implementing those standards. We would appreciate your reactions to our work as we journey toward improving mathematics and science for Georgia students.

Sincerely,

Wanda M White

Wanda M. White, Ph.D.

Georgia Initiative In Mathematics And Science

Dear Colleague,

This is an exciting moment for all of us committed to the best education for each Georgia student. More than sixty of our most successful teachers, district level professionals, curriculum specialists in colleges and universities, mathematicians, scientists, and other practitioners in the field have offered us their best thinking on learning and teaching quality mathematics and science. Their labor comes to us in the form of the Georgia Framework for Learning Mathematics and Science which is enclosed in this package. Included in this package is an **explanation** of what a curriculum **framework** is with a list of the **Georgians involved in development** of the draft and a **review form** for you to copy for reviewers in your system.

Now comes your turn: We owe it to the framework developers and to the thousands of Georgia students and teachers to consider carefully this work and make recommendations to strengthen the quality and usefulness of the framework. For parents, business people, and communities, this field review process is an important check on how these learning standards match their own expectations of the types of workers and citizens we desire for Georgia. For education professionals, this review process is an important check on needs within and around the education system to support the instructional vision for our children.

How can you help? We encourage you to share the draft of the Learning Framework with those who are concerned about education in your community. We are seeking input from as many different stakeholders as possible--classroom teachers, parents, students, Boards of Education, and business and community members. Would you set as a goal, 3-5 mathematics and/or science teachers, K-12, and representatives of the other groups? Ask each of them to complete both sides of the review form. You will need to copy the review form and we hope you will feel free to make additional copies of the Learning Framework. Please return the completed review forms by mail or fax.

The review process will be open through **28 February**. Following that, a Review Panel Committee will study each response in preparation for recommending revisions. The Georgia Department of Education Learning Framework Ad Hoc Committee is guiding the framework development through to presentation to the Georgia Board of Education in Spring, 1995.

In appreciation for your efforts, we will send you a copy of the Learning Framework that is presented to the Georgia Board of Education.

We need your review and input! We look forward to hearing from you!

Sincerely,

Michael J. Padilla

Michael J. Padilla
Principal Investigator

Georgia Initiative in Mathematics and Science • G-9 Aderhold Hall • Athens, GA 30602-7126 • (706) 542-4341 • FAX (706) 542-4348

The Georgia Framework for Learning Mathematics and Science

> *A ... framework specifies, organizes, and integrates the content and processes of education.... Its structure forms a bridge between established standards and classroom practice ...* (OERI. "A Summary of Analyzed State Curriculum Frameworks." May 24, 1993, p. 5).

The Georgia Initiative in Mathematics and Science (GIMS) is a collaborative endeavor among the Governor's office, the Georgia Department of Education, seven of Georgia's universities and colleges, Professional Development Schools, a broad array of education stakeholders in the state, and National Science Foundation. The **Georgia Framework for Learning Mathematics and Science** communicates the knowledge, skills and dispositions in science and mathematics necessary for all Georgia students. GIMS is developing products and processes to support learning in mathematics and science. The **Learning Framework** is one such product.

Attached is a draft copy of the **Georgia Framework for Learning Mathematics and Science** for your review. The purpose of this draft is twofold: To provide a vehicle for input from YOU and the Georgia education community and to stimulate conversation among the communities of people who care about science and mathematics education.. Following the draft review, the revised document will be presented to the Georgia Board of Education in early 1995.

Exactly what IS a framework? A curriculum framework reflects the policy and educational environment of a state. It is a dynamic tool to provide guidance for curriculum development, instruction and assessment at both the state and local level. A curriculum framework also represents opportunities for dialogue and professional development that encourage local decision making. A curriculum framework is NOT a curriculum guide. It addresses complex issues such as strategies, technology, assessment, and materials.

How will the Learning Framework be used? The **Georgia Framework for Learning Mathematics and Science** has been developed for multiple audiences. It will be used at the state level as well as in local school districts, schools, and classrooms. It will establish direction for local school districts in developing curriculum, providing professional development and creating environments, implementing strategies, and selecting teaching and learning resources (i..e., textbook selection) that will maximize learning for each student.

The **Learning Framework** is just the beginning. It represents the initial entry in the **Georgia Learning and Teaching Portfolio in Mathematics and Science.** The portfolio will include sample exemplary components to serve as models of effective practices for school districts as they begin to implement the **Learning Framework**. These exemplary components might be videotapes, audiotapes, hard copy, or diskette that provide examples of students engaged in learning activities, sample curriculum guides, exemplary assessment activities, model lessons, ... and other resources.

Georgia Initiative in Mathematics and Science • G-9 Aderhold Hall • Athens, GA 30602-7126 • (706) 542-4341 • FAX (706) 542-4348

Georgia Framework for Learning Mathematics and Science
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Booth Middle School

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Elementary Science
Coordinator
Atlanta City

GEORGIA FRAMEWORK FOR LEARNING MATHEMATICS AND SCIENCE

I. Please complete for NSF reporting purposes:

Gender: ☐ Female ☐ Male

Ethnicity :

☐ Asian/Pacific Islander
☐ Hispanic
☐ Native American
☐ Black/African American
☐ Multi-racial
☐ Caucasian

Are you an individual with a physical disability? ☐ No ☐ Yes

If you work in education, please go to Part III.

II. If you do not work in education, please describe the nature of your perspective.

☐ Community Member
☐ Parent
☐ Business/Industry - type or name ______________________
☐ Governmental/Legislative
☐ Other (please explain) ______________________

III. If you work in an educational agency, please indicate the agency/system ______________________ and check all that best describe your role:

☐ teacher
☐ student
☐ college/university administrator
☐ local/school administrator
☐ system administrator
☐ instructional supervisor

Please indicate grade level(s) applicable to your role :

☐ K-2 ☐ 3-5 ☐ 6-8 ☐ 9-12 ☐ college/university

The students for whom I am responsible can be described as follows:

Most of my students come from the following socioeconomic status(es):

☐ Low ☐ Middle ☐ High

They live in the following setting(s):

☐ Suburban ☐ Urban ☐ Rural

My students represent the following ethnicities:

☐ Asian/Pacific Islander
☐ Hispanic
☐ Native American
☐ Black/African American
☐ Multi-racial
☐ Caucasian

How many of your students are physically disabled? ____
How many of them are served by special education programs? ____
How many are Limited English Proficient? ____

Your input in the development of the Georgia Framework for Learning Mathematics and Science is important. Please complete this form and return to: GIMS/Framework, G-9 Aderhold Hall, Athens, GA 30602-7126; or fax to (706) 542-4348.

REACTION TO THE LEARNING FRAMEWORK DRAFT

1. What is the strongest aspect of the Learning Framework?

2. What did you like least about the Learning Framework and what would improve it?

3. What should have been included to enhance the quality of the Learning Framework?

4. What was redundant or where could it be shortened?

5. Are there any areas that are vague and need clarification?

6. Additional Comments (attach additional sheets as necessary):

If you would be willing for us to contact you regarding your comments or if you wish to receive additional information about the Georgia Framework for Learning Mathematics and Science, please provide the following information:

Name: ____________________________

Address: ____________________________

City/State/Zip: ____________________________

Please return by February 28, 1995 to:

GIMS/Learning Framework
G-9 Aderhold Hall
Athens, GA 30602

or fax to (706) 542-4348

GEORGIA LEARNING AND TEACHING PORTFOLIO

IN MATHEMATICS AND SCIENCE

In Georgia, teachers of mathematics and science, mathematicians, scientists, administrators, parents, students, representatives from business and industry, and community leaders have embarked upon an educational journey to develop a **Learning and Teaching Portfolio** for mathematics and science. The **Learning Framework** is the first entry in this portfolio. It is the articulated connection between national education standards and learning experiences for all Georgia students. It communicates a philosophical foundation for the mathematics and science education for all Georgia students.

The **Georgia Framework for Learning Mathematics and Science** communicates the knowledge, skills, and dispositions in science and mathematics necessary for all Georgia students. It also highlights instructional practices, materials, and assessment strategies that will be needed to support their implementation. The **Learning Framework** will serve to implement the National Council of Teachers of Mathematics' standards and emerging national science standards for all Georgia students. The **Learning Framework** is based on the belief that children learn in different ways, at different rates, and for different reasons: that learners require active participation in learning and that developmentally appropriate learning experiences are important.

The **Learning Framework** links national standards to classroom practice in Georgia by:

- Identifying essential understandings of mathematics and science for Georgia's students to learn,
- Presenting examples of high quality instruction and assessment,
- Guiding the selection, development, and management of learning resources,
- Providing guidelines for the types of physical environment most supportive of learning mathematics and science,
- Establishing criteria upon which professional development programs will be based,
- Indicating guidelines for appropriate use of technology including distance learning,
- Describing a learning environment that values each individual student.

GIMS Learning and Teaching Portfolio, G-9 Aderhold Hall, University of Georgia, Athens, Georgia 30602-7126

The Georgia Learning and Teaching Portfolio is a collaborative effort between the Georgia Department of Education and the Georgia Initiative in Mathematics and Science. It is being developed by mathematics and science teachers, mathematicians, scientists, parents, representatives from business and industry, and community leaders.

As education reform matures and more about this journey is clear and sure, the **Learning Framework** will be joined by other resources to form a **Learning and Teaching Portfolio**, supporting reform in mathematics and science education in Georgia. The **Learning Framework** and the other entries in the **Learning and Teaching Portfolio** will be available to all concerned citizens.

The **Learning and Teaching Portfolio** must contain a wide variety of examples and models as we help classroom teachers implement the philosophy and vision of education reform in Georgia schools. We need your help in identifying and developing these elements of the **Teaching and Learning Portfolio**. With the **Learning Framework** as a shared foundation for transforming science and mathematics for all Georgia students, the bricks and mortar needed to complete our work must come from you. What are the tools and connections to take the spirit of the **Learning Framework** and make it work for all teachers and all students? What are the model lessons, the sample assessments, the instructional management techniques, the class and school organization, the professional development opportunities, and community connections and programs which can be included in the **Learning and Teaching Portfolio** to fully articulate our vision for education reform in mathematics and science?

We need your ideas to enrich education for all students. We need your examples, models, and products that effectively transform teaching and learning in mathematics and science. Take a moment and reflect on those tools, techniques, connections and strategies which have made reform meaningful for you. Share your products on diskette, videotape, audiotape, paper, ... Questions? You can reach us via:

Snailmail	GIMS Learning and Teaching Portfolio G-9 Aderhold Hall University of Georgia Athens, Georgia 30602-7126
Email	GIMS@UGA.CC.UGA.EDU
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Let us hear from you!