Getting Real About Implementing Reforms for Pre-College Math and Science Education:

Classroom Instruction, Student Motivation and Accountability

JOHNS HOPKINS UNIVERSITY
James McPartland, Allen Ruby, Vicki Hill & Danny Jones

3rd Annual Johns Hopkins Education Summit
“Accelerating the K–12 Mathematics and Science Curriculum: Agenda for the 21st Century”
May 23, 2006
Baltimore, Maryland
# Table of Contents

1. **Recommended Reforms** .......................................................................................................................... 1  
   
   **Curriculum**  
   1. Balance skills and understanding ................................................................................................................. 2
   2. Start early .......................................................................................................................................................... 3
   3. Coordinate the subjects ............................................................................................................................... 4
   
   **Instruction**  
   4. Follow learning principles ............................................................................................................................ 4
   5. Minimize repetition, maximize new knowledge across the grades ............................................................... 5
   6. Use technology wisely ..................................................................................................................................... 6
   
   **Equity**  
   7. Flexible resources to close skill gaps .......................................................................................................... 7
   8. Increase representation of women and minorities ....................................................................................... 8
   
2. **Classroom Instruction** ............................................................................................................................... 9
   
   A. Staffing and deployment of expert teachers ................................................................................................. 11
      Current elementary, middle and high school grades staffing patterns ......................................................... 13
      Re-deploy Expert Teachers .......................................................................................................................... 15
   
   B. Completeness of lesson materials .............................................................................................................. 19
   
   C. Professional Development and Continuous Support for Teachers ............................................................. 22
      Effective workshops ........................................................................................................................................ 22
      Expert coaching ............................................................................................................................................... 23
      Teacher networks .......................................................................................................................................... 24
   
   D. Combining Innovations in Staffing, Daily Lessons, and Coaching in Different Districts ........................... 26

3. **Student Motivation and Equality of Opportunities** ............................................................................... 27
   
   A. Closing skill gaps ........................................................................................................................................ 27
      Early Foundation ............................................................................................................................................. 28
      Extra time and extra help in the upper grades ............................................................................................. 29
   
   B. Attracting Under-represented Groups ........................................................................................................ 36
      Career Awareness ......................................................................................................................................... 37
      Career focus for high schools ..................................................................................................................... 37
      Blended instruction ..................................................................................................................................... 40

4. **Accountability** .......................................................................................................................................... 42
   
   A. Good teaching as the best test preparation ................................................................................................. 44
   
   B. Expanding the assessment package ........................................................................................................... 46

5. **Summary** .................................................................................................................................................. 53

REFERENCES .................................................................................................................................................... 50-51
Implementation is at the heart of successful mathematics and science education reforms. Implementation means actually putting in place the recommended math and science reform policies and programs. When implementation is strong, the intended changes for math and science instruction really happen in the targeted schools and classrooms.

Very often failures in reform are not because the recommended math and science improvements did not have the potential for powerful positive effects, as may have been shown by impressive evaluations of small demonstration sites. Failures are more often caused by surrounding conditions that thwart the intended changes or by the inabilities of the persons on the ground to implement the reforms.

This presentation examines the implementation requirements of some major recent recommendations to upgrade pre-college math and science education in this country, with some practical ideas to make the change processes be successful.

The first section briefly outlines some major recommendations to reform K–12 math and science education, and some of the implementation challenges involved.

The following three sections discuss the implementation issues with some practical suggestions concerning (a) classroom instruction: how to implement better lessons by the available teaching corps; (b) student motivation: how to get students from all population groups interested in working hard on math and science; and (c) accountability: how to structure state requirements and tests as positive incentives for excellent instruction in math and science.

1. **Recommended Reforms**

What will it take to make the recommendations for pre-college math and science reforms actually happen in America’s schools and classrooms?
The implementation challenges become clear when some recent reform recommendations for pre-college math and science education are listed in detail. Reforms are being sought for curriculum, instruction and equity.

**Curriculum recommendations**

1. **Balance skills and understanding.** Learning goals should balance student growth in basic skills and content knowledge with development of higher order conceptual understandings and applications.

   In mathematics, students should not only be able to complete arithmetic calculations and apply core algorithms easily and correctly, they should also know the conceptual foundations of these skills so they can approach unfamiliar problems with appropriate mathematical formulations and be able to check their answers and monitor their progress with confidence.

   Just where the balance between computations and concepts should be struck has been the subject of some intense “math wars” between mathematicians and math educators (Schoenfeld, Loveless, 2001; Klein, et al. 2005). But consensus is growing that both need major emphasis and indeed that strength in one area can lead to strength in the other (Ball, et al. 2005; Seeley, 2006). When students can compute easily, they are free to think about the concepts underlying the numbers and to check their answers with good reasoning. When students understand the conceptual underpinnings of core math topics, they can avoid typical computational mistakes—such as applying the number sense of counting learned in whole number arithmetic when working with fractions and percents where multiples and ratios apply.

   In science, all students should know the core facts in biology, physics and chemistry, but also learn about scientific method and the discovery processes that produce new knowledge. Competing goals of science education exist, just as in math. Science can be seen as a structured body of knowledge, logically organized and primarily concerned with facts and the underlying
principles and theories. Under this view, the goal of education is to give the student a firm grounding in these basics. Another goal is to provide the student with an understanding of what science is and how it works. Under this goal, science instruction includes how science is carried out, the nature of scientific knowledge and how it is accepted and changed, the habits of mind scientists use, often with historical examples to illustrate these. A third goal, seemingly related to the second but often quite separate, is to teach students the individual skills and techniques of science as an investigative process. These skills are to help a student contribute to the body of scientific knowledge and form a tool the student can use in daily life, be it for personal decisions, at work or in an attempt to solve societal problems. A fourth goal is to provide an applied education linking science either with meeting individual needs (e.g., understanding proper nutrition or providing employment-related technical applications) or addressing societal issues, (e.g., reducing pollution). The applied approach also aims to increase student interest in science by making it relevant to daily life. These goals compete for instructional time and treatment, so balances should be reached.

2. Start early: Instruction in both skills and understanding should begin in the early grades, through continuous balanced lessons appropriate to students’ age and developmental levels.

In mathematics, the core notions of variables in equations and graphic representations of frequencies and relationships can be appropriately introduced with early grades instruction in whole number arithmetic, integers and rational numbers, so algebra is gradually learned and understood without abrupt shifts in later grades.

In science, we should be able to build on the inherent curiosity of young children about how the natural world works, instead of marginalizing science instruction in the early grades and
rarely challenging students’ minds to explore and make sense of something new in the upper grades.

3. **Coordinate the subjects:** Math and science learning should go hand-in-hand across the grades, so the language and tools of mathematics are directly used for understanding and applying science.

Math and science courses should share topics and bring the teachers together to plan lessons.

**Instructional recommendations**

4. **Follow learning principles:** Classroom learning activities should be designed in light of how humans learn, building upon background knowledge and experiences, balancing facts and concepts, and helping students monitor their own progress with appropriate learning strategies.

Studies have shown that it is easier to learn math when students use familiar images (such as the measured line for integers or starting with percents in rational numbers, or using the context of a walkathon as a bridge for functions), and when hands-on manipulatives, mental math estimation of simple problems, and teacher-guided student team discussions are used in instruction (National Research Council, 2005).

Likewise in science, lessons have been found to be more effective when students’ correct and incorrect preconceptions of specific scientific phenomena are assessed and directly addressed in instruction, and when opportunities are provided to gain scientific knowledge through an inquiry process that uses data to decide between competing explanations or to estimate relationships of cause and effect.

5. **Minimize repetition, maximize new knowledge across the grades:** The pace of instruction across the grades should be accelerated, so review does not outweigh new material that challenges students and moves learning forward.

In mathematics, the average American student does not receive pre-college instruction in Algebra 2 (including completing the square of quadratic polynomials, derivation of the quadratic
formula and graphic applications of conic sections) much less pre-calculus and calculus, because mathematics learning does not progress purposefully across elementary and secondary grades. Designing math instruction at each grade level away from heavy review and repetition toward a press for teaching the next topic in the math sequence is needed to reach the higher learning goals.

Some recent studies using video tapes of math and science instruction in different countries document problems in typical American classrooms of lack of balance between skill practice and conceptual understanding and of repetition of old material before introduction of new. In mathematics, video examples from eighth grade math classroom this county were compared to six other countries where students out-performed American students on international math achievement tests. A general pattern of differences was found where American classroom practices devoted more time to reviewing old material than introducing new topics, focused more on skill development without the conceptual foundations, and used less student team cooperative learning and discussions of math problems (Hiebert, et al., 2005).

A similar video study of eighth grade science classrooms in five countries found that U.S. science instruction often fails to link lessons to the larger science concepts. Compared to four higher-achieving nations, U.S. lessons are often focused on discrete facts and definitions. On the other hand, America science teachers are using more multiple instructional approaches (practical activities, seatwork, whole-class discussions) and emphasize the use of techniques to increase student interest such as hands-on activities, real life issues and games or activities. But when real life issues are used to engage student interest, these are not linked by American teachers to the larger science content ideas (National Center for Education Statistics, 2006).
6. **Use technology wisely:** Instructional technology, such as calculators and computers, should be used to encourage deeper understandings of core concepts and relationships, but after students have become proficient in basic computations using standard algorithms.

Before relying on calculators in mathematics, students should first memorize multiplication tables, number combinations, and benchmark fraction-decimal equivalences and use practice drills to reach fluency with core operations in arithmetic. Paper and pencil exercises with tables, graphs and formula representations of functional relationships should also precede extensive use of graphing calculators. But when basic skills have been established, technology tools can be valuable to deepen understanding. Instructional computers can simulate the graphic movement of changing functional values and focus attention on math reasoning and problem solving.

In science, technology offers several opportunities for improved instruction (Klahr, Triona, & Williams, 2006), but questions also arise of bringing technology too early in the classroom. Data for scientific analyses can be made readily accessible with technology in the classroom or science lab, through internet access to real-time information on scientific phenomena, by use of measurement equipment linked to computers for creating reliable dynamic data bases, and by participating in national surveys and adding local information for comparative perspectives. But the initial use of traditional hands-on instruments for data collection may be the best instructional approach, such as measuring with thermometers before temperature probes linked to computers. Computer simulations of scientific concepts and relationships can also aid student understanding by demonstration not usually observable in the classroom or by modeling outcomes from changing values on selected variables in complex systems. But hands-on experiments with familiar objects may give students a chance to notice relevant factors that would be missed in preprogrammed simulations, such as work with levers or racing cars in
physics. More research is needed in science education to evaluate the best place of technology for instruction.

**Equity recommendations**

7. **Close skill gaps linked to students’ background.** The large skill gaps in math and science that develop between schools and individuals from different socio-economic levels should be narrowed and closed over the elementary and secondary grades, so all individuals have opportunities to enter advanced work and careers in these fields.

The average student in many high-poverty high schools enters more than 3 years below grade level in mathematics. To graduate four years later ready for college, these students must greatly accelerate their rate of learning to add important skills they missed in earlier grades and to master the challenging advanced math topics of their upper grades. The average skill gaps exist from the beginning of schooling and do not narrow—and sometimes grow—over the grades.

In science, there is the added burden that poorly prepared students cannot read the high school textbooks for recall and understanding of science units. Approaches are needed to fix this content literacy deficiency as well as to otherwise provide science learning experiences at the highest level for all students.

8. **Increase representation of women and minorities:** All race-ethnic and gender student groups should be given opportunities to develop strong interests in math and science careers and to become highly engaged in learning activities in related subjects across the grades (Schoenfeld, 2002).

Although the number of females and males in higher education has become nearly equal in recent years, the large proportional under-representation of women in math and science majors and careers has remained (Educational Testing Service, 2005). Major race and ethnic minority groups are still significantly missing in both representative numbers and proportional distributions for advanced work in math and science.
Putting recommendations into practice:

This collection of recommendations to upgrade pre-college science and math instruction will be difficult to widely implement for several reasons.

The curriculum and instruction recommendations require high levels of teacher expertise across the grades that are now not widely available. The practical implementation questions are how can teacher expertise be increased by recruiting more successfully from different sources, or how can current teaching talent be deployed to different roles for best results? Also, are there better ways to get the most from the current teacher supply through more ready-to-use classroom lessons or greater coaching support?

The equity recommendations lead us to ask why too few American students are interested in math and science, especially poor and minority students with major skill gaps in these subjects and many female students who retain traditional views of careers for women. Several major practical implementation questions arise. How can more students be motivated to develop high-level math and science competencies? What instructional programs can close skill gaps so all students can do well in these subjects? How can links be established between broader career goals of each student group and relevant math and science learning?

Accountability systems will influence classroom instruction reforms. How can federal and state standards and tests encourage districts and schools to focus instruction on both skills and conceptual understanding for all students?

The remaining sections of this paper explore a variety of ideas for implementing the major curriculum, instruction and equity reform recommendations. Practical considerations will be offered for staffing, providing lesson materials, and designing professional development for the desired classroom instruction. Alternatives will be suggested for directing extra time and
resources to needy students and for offering more relevant learning activities to increase student motivation across all race-ethnic and gender student groups. Finally, different ways will be examined of designing external accountability systems to stimulate the best instructional and motivational approaches.

2. Classroom Instruction

The implementation problems derive from the expertise needed to provide learning activities in math and science for developing both basic skills and deeper understanding, and the current shortage of teachers now ready to deliver such instruction across the grades. These problems are multiplied when the reform goals include greatly enhancing instruction in the early grades where specialist teachers in math and science do not now exist, and expanding instruction in the upper grades to include a balance of traditional skills, and conceptual understanding in lessons when most current teachers came up through traditional education and training.

The solutions will come from creative combinations of (a) recruiting, retraining and strategically deploying more expert science and math teachers, (b) providing detailed daily lesson materials to guide balanced instruction, and (c) supporting teachers with ongoing professional development and coaching.

Figure 2 outlines the implementation issues we will discuss for improved classroom instruction.
A. **Staffing and deployment of expert teachers**

America now has a serious shortage of teachers who majored in math or science, especially in high-poverty districts and schools. This situation will become even worse if policies are pursued to include math and science specialist teachers in the elementary grades.

The most frequent discussed solutions are to recruit many more highly-trained math and science teachers and to strengthen the skills of the current teachers in these subjects. For example, a recent report sponsored by the National Academies recommends generous college scholarships to recruit 10,000 new science and mathematics teachers each year, and summer institutes and masters programs to upgrade the skills of 250,000 current K–12 teachers (Committee on Prospering in the Global Economy, 2006). But we also need to think creatively about how to better deploy math and science teachers with different levels of training and expertise into different instructional and support roles for more effective math and science instruction.
It cannot be assumed that the shortages of very well-prepared math and science teachers will be solved very soon through better recruitment and training, which will be extremely costly and must compete with the great demands from industry for the same individuals. So it is wise to think about better ways to distribute the expertise of current and likely new teachers for high-quality instruction across the grades.

Current staffing practices across the elementary, middle and high school grades usually do not take into account different levels of teacher preparations or expertise in math and science, so the quality of instruction in these core subjects is often compromised to other educational goals or focused on grades or selected students.

Current elementary, middle and high school grades staffing patterns

The American education system takes a child-centered approach in the way elementary schools are usually staffed, by having a single teacher with a self-contained class of students covering all the major subjects of instruction. Having one teacher responsible for a single class of students permits the personalization of instruction and attention to individual needs that many believe works best for students of this age. Thus, for the early grades, teachers are certified for general elementary school instruction rather than as a specialist in a single subject as is the case in the high school grades. Consequently, each individual elementary grade teacher is expected to provide excellent instruction in both literacy and mathematics, as well as whatever science and social studies or history can be worked in. To narrow the instructional challenges, elementary teachers often become specialists in one particular grade, so they can be strong with the particular instructional areas in each subject for that year of schooling. But there is concern that under this arrangement, math and science education is much weaker than reading and language arts in the elementary grades. Any recommendations to greatly accelerate the coverage of math
and science units in the elementary grades will be frustrated by the absence of subject-matter expertise in these areas among elementary certified teachers. We will consider alternative staffing arrangements for the elementary grades where more subject-oriented expertise can be brought to bear in math and science without sacrificing the degree of adult personal attention and classroom cohesion that works well for younger students.

Current staffing in the middle grades 6 through 8 is often no better, with many teachers also having general elementary education certification and training rather than specializing in one subject. Again, math and science instruction often continues to take a back seat from generalist teachers who feel most comfortable with language arts subjects. In the attempt to upgrade math and science instruction in the middle grades, some schools introduce “semi-departmentalization,” where the existing teachers divide themselves into two groups of math-science specialists or English-social studies specialists, so teachers can concentrate on fewer subjects and students can change classes only once or twice per day to be taught by these specialists. This arrangement is seen as a balance between the child-centered personalization of the early grades (since the number of separate teachers per student is limited to two) and the subject-matter specialist emphasis of the upper grades (since each teacher concentrates on two subjects rather than all subjects).

When middle schools are larger and can assign each teacher to one major subject in each grade, “interdisciplinary teams” are often formed of 4 teachers who share the same set of 80-to-120 students to balance the personalization and specialization goals of instruction. When each middle grades team is given common planning time to work together on individual student problems, the child-centered goals can be addressed at the same time as the specialized instructional classes can be offered in each subject (McPartland, 1990). But certification and
training in a specific subject is still not usually required to teach in the middle grades, so math and science teaching may still be poorly staffed even when semi-departmentalization or interdisciplinary teams is used in these grades. One obvious recommendation is to require specific math and science training and certification for teachers in grade 6 and above, and use teacher teams to personalize relationships with their shared students. Indeed, federal regulations under NCLB will soon require subject matter specialists for Grade 8 teaching.

In the high school grades where subject-matter certification of teachers is always required and departments are formed for instruction by specialists in each discipline, there are still major problems of teacher shortages and limited prior preparations in American schools. Studies show that high school teachers are often assigned outside of subjects where they had been trained, or are not fully certified in the subjects they teach, especially in many high-poverty districts and schools.

Moreover, the most experienced and well-trained high school teachers often opt for the upper grade and advanced math and science courses, leaving the ninth and tenth grade foundation courses to more novice teachers.

The problems of teacher preparation in math and science also arise from the instructional demands of balancing student understanding of core ideas and conceptual foundations with student skills for computational fluency and factual recall where traditional teacher training has concentrated. Evaluations of various balanced mathematics curricula have noted teacher difficulties with implementing the recommended learning activities—such as not completing the year’s work or adapting and distorting the reform recommendations to sort themselves (Kilpatrick, 2003; Romberg & Shafer, 2003). How can teacher expertise with balanced instruction be further developed and better deployed to benefit all students?
Re-deploy Expert Teachers

Assuming that it will be some time before recruiting and retraining deliver enough expert math and science teachers in all grades, we need to consider how the distribution of teacher expertise can be better deployed for high quality pre-college math and science education across the board. Figure 3 outlines some ideas for re-deploying math and science specialists at each grade level.

Perhaps more high-quality math and science instruction can be achieved by having teachers of each subject work together at their school to coordinate instruction that uses different levels of existing expertise to distribute different instructional activities. Sometimes the teachers may decide that a hierarchical division of labor fits their distribution of expertise in math or science, where master teachers from the team take more responsibility for offering the laboratories or learning activities focused on discovery and conceptual understandings. In these cases, “team teaching” in each subject may work well where each class receives instruction from a master teacher and from a regular teacher who work closely together to coordinate lessons and support one another. At other times, teachers may work in two-person teams to trade off responsibilities on different course topics during the year for conceptual lessons that need more preparations and computational or factual lessons that follow. Again, time for cooperation and coordination must be made available.
In the grades K–5, differentiated instruction for math and science could use one or more specialists in each subject to visit one or two days per week for instruction on conceptual understanding that can be more difficult to teach. Follow-up instruction would occur on the remaining days of the week by the homeroom teacher giving guided practice of computational or knowledge recall. To make this division of labor smooth and complementary, teams of teachers led by the math or science specialists could coordinate instruction to balance the skill and understanding goals.

Consider an elementary school with two homerooms in each grade, a total of 10 classrooms in grades 1 through 5. A math specialist could conduct a weekly lesson for each of the 10 classes, with time to visit each homeroom teacher’s follow-up classes at least one additional time per week. The regular classroom teacher would also attend the master class with the students and the expert teacher, to co-teach, assist or observe the lesson. There would still be time available for the expert teacher to meet with each grade level team to coordinate instruction and preview lessons.
As science is introduced in the upper elementary grades, a similar arrangement could be worked out with a specialist teacher leading and coordinating instruction with the regular homeroom teacher.

In the middle grades, new requirements for subject-matter certification will gradually increase the supply of teachers with specialized training in math or science education. Then the transition from semi-departmentalization in Grade 6 to full departmentalization of single subject specialists in Grade 8 can become common. With full departmentalization, interdisciplinary teacher teams sharing the same students with a common planning period becomes the key to effective middle grades instruction. A team of four teachers from each major subject can meet together to personalize the learning environment and to solve individual problems of their shared students, at the same time they are prepared to provide specialized expertise in the core subjects. Sometimes the middle grade team can also coordinate instruction across the major subjects with a shared theme or with shared emphasis on reading skills needed in each course. Interdisciplinary teacher teams are most often found in the middle grades, but also can be a very valuable staffing arrangement for the transition grade in high school. (Kerr & Legters, 2004).

In high school, more differentiated staffing should also be considered. Expert master teachers with advanced math or science training for conceptual understanding lessons could lead the effort. They would support the by regular science and math teachers who may be more confident with more traditional lessons of computation drill and factual recall. By matching the dimensions of teacher expertise with different learning goals and activities, the available staff can be best deployed so that all students have the opportunity to learn basic skills and facts along with the conceptual foundations that support the skills.
Think of a high school with 300 students at each grade. A specialist who conducts 15 extended period classes per week (3 classes of 20 students per day) could service all students in a grade with one master class in math or science each week. In smaller high schools, where the master teacher would need to service two grades, careful scheduling would help them get ready with outstanding master classes. All the local teachers themselves should work out the ways a master teacher can be most helpful in each subject, so any lead lessons or shared instruction is welcomed and supportive in each case.

In science, the laboratory lessons offer various possibilities for deploying teachers with different kinds of expertise (Singer, Hilton, & Schweingruber, 2006). Labs could be conducted by specialist teachers who only conduct laboratory lessons or be a shared instructional activity with the two teachers. When differentiated staffing for laboratory lessons is used in science courses, it is important to coordinate all instruction by including everyone in the lab sections or other means to link all lessons.

Support for differentiated staffing can be worked out with the teacher unions, since the ideas for master teachers, instructional specialists working with regular classroom teachers, and career lines within teaching have been discussed over the years by AFT and NEA leaders (AFT, 2002). Regular time for teachers to plan together within subject-matter groups and to coordinate across interdisciplinary teams will be required to make creative staffing arrangements work well in the classrooms.

**B. Completeness of lesson materials**

Another point of view is that providing complete daily lessons for existing teachers is more promising than waiting to find more expert teachers for every classroom.
If specific outlines of daily lessons are provided to teachers complete with materials and directions for student hands-on activities as well as handouts and overhead transparencies to direct instruction, excellent learning activities that balance skills and understanding may be within reach of most teachers who now rely on traditional textbooks for their own lessons. Preliminary evidence comes from our own recent experiences at Johns Hopkins and from recent National Research Council reports to support better daily lesson materials as a key route for reforming math and science education. The emphasis on outstanding daily lessons is also a feature of math and science education in Japan and of some recent curriculum development efforts in this country.

We have written three high school math courses as first-term transition offerings for Algebra 1, Geometry and Algebra 2. They provide very detailed daily lessons intended to allow the average existing teacher in our partnership schools to implement sophisticated learning activities that stress deeper understanding of core math concepts. We find that even marginal math teachers, whose previous training was weak or concentrated on traditional drills, can implement these lessons effectively with a reasonable amount of training and coaching. These daily lessons give detailed directions and timing for specific learning activities and complete supporting materials, but do not go so far as to offer verbal scripts to be read by teachers, which may be resented as insulting to a teacher’s professional status. Examples of these lessons will be available at afternoon sessions of this conference.

A recent (2005) National Research Council report takes the daily lesson as its unit of analysis to show what careful planning is needed to develop the specific learning activities that can help all students understand core concepts in math and science. Detailed learning activities are shown for whole-number sense in primary grades mathematics, and for the rational number
system of fractions, decimals and percents, and functional relationships in the later grades mathematics. Science lessons are also shown for scientific knowledge and reasoning about light in elementary grades, and for gravity and its effects, and genetics models in later grades. These are examples of lessons that use basic principles of human learning to build upon existing student knowledge and experience, balance skill fluency with conceptual understanding, and provide strategies and tools for self-monitoring of learning with corrective actions when appropriate.

NSF has supported the development of several new math and science curricula to balance skill development and conceptual understanding, but these vary widely on the specificity and completeness of daily lesson materials. Studies have often found that these new curricula are not easily implemented by the average math or science teacher, even with considerable professional development support (Kirkpatrick, 2003; Romberger & Shafer, 2003). Our own informal survey of high school math teachers in Philadelphia strongly favored the one NSF curriculum that offered the most specific daily lessons and supporting material over other packages that covered similar content and pedagogies but required the teachers themselves to work out many daily lesson details. Even the existing NSF reform curriculum with the most detailed and complete daily lessons does not reach the level of specificity and depth of the examples in the 2005 National Research Council report. We recommend that further federal and commercial investments in curricula for math and science instruction focus on the daily lessons to create classroom activities that follow human learning processes and that can be readily used by the average teacher with a reasonable professional development support.

The development and refinement of daily lessons is at the core of math and science education in Japan, which is one of the highest-scoring countries in international test
comparisons. The Japanese example has prompted attention to lesson study as a form of professional development to improve math and science education in America (Lewis, Perry & Muratai, 2006).

We believe that the development of collections of effective daily lessons for math and science courses at each grade level, with detailed learning activities and complete supporting materials, is a major part of the solutions to shortages of expert teachers and the need for balanced instruction in these subjects. Attention and investments in building such collections of effective daily lessons should come from federal programs, commercial publishers, and states and school districts.

C. **Professional Development and Continuous Support for Teachers**

Although reformers invariably call for excellent professional development to help teachers implement improved instruction, such programs are unlikely to bring about real change unless initial workshops are followed up by focused support throughout the year from local networks of teachers or expert collegial coaches. Too often professional development in American schools means a single day of “hit and run” workshops by outside speakers without any follow-up. Instead, our experience with helping math and science teachers implement instructional innovations shows the need for workshops that combine theory and practice, followed up by continuous use of expert coaches who regularly visit teachers’ classrooms and time for teachers to work together in departments and network with others in their district (Desmione, Porter, Garet, Yoon, & Birman, 2002).
Effective workshops

One- or two-day workshops can launch an effective program when teachers come away with practical instructional innovations and understand why these approaches will improve student motivation and learning. Such workshops will combine the learning theories that justify the recommended changes and actual practice with the new classroom approaches.

The foundations for math workshops may include recent studies of how humans learn. These studies indicate that lessons work best when they address students’ initial knowledge or preconceptions, combine skill-building with conceptual understanding, and equip students with ways to check their answers to selected math problems. If the math unit happened to be rational numbers, the workshop could begin with an analysis of student errors when they incorrectly count from whole number arithmetic instead of the understanding of multiples and ratios for operating with fractions, decimals, and percents. Examples are offered in the National Research Council’s report on science lessons that work from students’ initial ideas to build the proper conceptual understandings for selected science knowledge (NRC, 2005).

Rationales from learning theories for new instructional approaches should then be followed by extensive practice in the workshop with complete classroom lessons. Participating teachers may play the roles of students as the workshop leader demonstrates the lesson. Video presentations of several lessons with students can be shown and critiqued by workshop members for strengths and weaknesses, where the segments are prepared beforehand to show some subtle differences between lessons where students are merely entertained versus where they learn and reflect on new knowledge. During workshops, teachers can work in small groups to design a lesson for a designated topic that can be demonstrated to others for practice and discussion.

At Johns Hopkins, math and science workshops for our model middle schools occur not
only for the beginning of the term, but also for 3 hours each month throughout the year on Saturdays or after school. These sessions focus on the unit or lessons the teachers will be using the following month. Key classroom activities are previewed and modeled, core content knowledge reviewed, and appropriate classroom management strategies discussed (Balfanz, Mac Iver, & Byrnes, 2006).

**Expert coaching**

At Johns Hopkins, we have used carefully trained coaches to work closely with teachers in our partnership high schools to implement instructional innovations in math. The coaching services are interspersed with monthly two-hour workshops where all teachers discuss recent activities that are working well or those that need closer attention. They also preview the lessons for the next few weeks. Coaches then visit each teacher’s classroom at least once a week to assist with lesson implementation. The assistance may be model teaching or co-teaching a lesson segment, discussing afterward the lesson’s effectiveness for specific learning goals, or suggesting alternative approaches when appropriate. The coaches have been extensively trained not only in the recommended delivery of specific learning activities, but also in the collegial role that respects a teacher’s professionalism and treats all interactions and observations as confidential without any input to teacher evaluation processes.

American schools use various coaching models (Munro & Elliott, 1987; Neufeld & Roger, 2003; Russo, 2004). The Boston model of collaborative coaching uses an expert in planning and teaming to work with interdisciplinary teacher groups on school improvement recommendations, such as literacy across the curriculum (Guinney, 2001). Some other districts invest in expert coaches in each major subject to work with numerous school faculties for general reform workshops and follow-ups. At Johns Hopkins, the coaching approach for our
Talent Development reform model assigns one full-time person in math or English to visit each middle or high school teacher in one or two schools at least one period a week to focus on individual lessons. The Talent Development model approach is costly, but it has proved successful for powerful implementations of innovative practices.

**Teacher networks**

Teacher networks in their own subject at their school or across schools can also be a valuable source of regular support and practical suggestions for implementing instructional innovations. All teachers with the same courses can meet to share successful techniques and to propose lesson modifications as improvements for the future. Coaches or master teachers can also contribute to these networks.

When multiple schools in the same district are implementing the same curriculum, teachers in each course can form a learning community to share implementation details and management strategies. Opportunities to meet in person can be supplemented by internet chat rooms where helpful communications can continue for stronger implementations.

**D. Combining Innovations in Staffing, Daily Lessons, and Coaching in Different Districts**

No single strategy will work the same way for every American district and schools. Large variations exist in their abilities to recruit and hold expert teachers and to afford new curriculum lessons or extensive coaching services. But each of these approaches should be in the reform arsenal at every location, because the risks are too great that math and science reforms will fail due to weak classroom implementations. Each of these recommended approaches—more expert staff wisely deployed, more complete daily lessons, and continuous support for teachers—is
expensive. In budget-strapped locations, the last allocations and the first cuts are often for costly coaches and extra time stipends for teachers to work together on lessons. Resources must be found from expanded federal, state and foundation sources and from local education expenditures for these essential components of powerful implementations of needed classroom reforms.

4. **Student Motivation and Equality of Opportunities**

Too many American students do not take to their math and science classes because they find these subjects irrelevant to their own goals, boring in how they are presented or because the students lack confidence in their abilities to handle the work. If the pipeline of students heading for serious college work in math and science is to be significantly expanded, our elementary and secondary schools must find ways to make these subjects more relevant and interesting, as well as more accessible and challenging to the average student throughout the country.

The serious under-representation of women and minorities in science, math and engineering careers continues to be a major problem in this country. This begins in the elementary and secondary grades when student interests and preparations for different career goals evolve. The minority students’ pipeline to math and science careers is short-circuited by the major skill gaps that develop in these areas. These gaps discourage or prevent entrance and success in the necessary college majors. Socialization and orientation are more likely to restrict female students who can do well in math and science courses but often turn away from the careers where men have traditionally dominated. What can be done to narrow and close the skill gaps in math and science between student subgroups and to breakdown the stereotypes and make study in these fields more appealing to both females and males?
A. **Closing skill gaps**

Minority students are more likely to be in high-poverty situations, where their families have fewer economic and educational resources and their schools are ill-equipped and low-performing. This combination leads to the major skill gaps between the more affluent student and many race-ethnic minority student groups. The gaps are not only in specific math skills and science knowledge, but also in the literacy skills needed to handle assigned textbooks in these subjects and to show what has been learned on written tests.

Problems of self-confidence as a learner can also intrude for closing skill gaps in math and science. The abstract thinking and symbolic language in these subjects may seem more foreign to students who are not from college educated families who can more easily assist their sons and daughters in these aspects of math and science study. Poor grades and learning struggles in earlier grades can also sap a student’s confidence that they can ever think well in math and science courses and handle the required work.

Three approaches need to be expanded in America’s elementary and secondary schools if the major skill gaps are to be narrowed and closed: build a strong foundation in the early grades, provide extra time and focused extra help to the most needy students across the grades and directly teach content literacy skills in reading and writing for math and science courses.

**Early Foundation**

We discussed earlier how many American students get off to a shaky start in math and science because of limited curriculums in the early grades. We offered some suggestions for deploying expert math and science teachers in elementary schools and providing more complete math and science lessons for the homeroom teachers to upgrade early instruction in these key subjects.
This afternoon, separate sessions will be offered on introducing math and science in Pre-K programs, and on how elementary grades math and science is taught in Success For All elementary schools, which is one of the most widely used and effective reform programs in this country.

Extra time and extra help in the upper grades

While better instruction in earlier grades should prevent many learning problems later, solving skill gap problems is not as simple as many believe. A strong foundation in the early basics of whole number arithmetic does not guarantee rapid understanding of fractions or functions later. Moreover, the background effects of poverty do not go away and continue to put students at a disadvantage for success in the later grades. For many poor and minority students, schools cannot rely on an “inoculation” theory that strong early interventions alone will prevent the skill gap. They must envision a continuous “booster shot” program, paying attention to closing gaps at each stage of school. In any case, many poor and minority students enter middle and high school far behind in math and science knowledge and skills. We can’t sacrifice another generation while we wait for stronger elementary grades to address these problems.

We will use the example of high school instructional innovations developed at Johns Hopkins University for our Talent Development reform model to describe how extra time and focused extra help can be used to narrow and close skill gaps that still exist at Grade 9 and beyond.

Our Talent Development approach is to accelerate the rate of student learning by doubling the amount of time in math instruction and by using first-term transition courses that lead into second-term high-standards Algebra and Geometry courses. The first-term transition courses fill in prerequisite skills and concepts that are the foundations for Algebra or Geometry.
These courses use learning activities of high interest to students to help them think like mathematicians. Table 4 outlines the Talent Development transition approaches at each high school grade. These course materials will also be presented and discussed in one of the afternoon sessions at this conference.

<table>
<thead>
<tr>
<th>Grade</th>
<th>First Term (18 weeks)</th>
<th>Second Term (18 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>“Transition to Advanced High School Math” (TAM)</td>
<td>Algebra 1</td>
</tr>
<tr>
<td></td>
<td>Topics include: Measurement, Rational Numbers, Language of Math, Functions</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>“Geometry Foundations”</td>
<td>Geometry</td>
</tr>
<tr>
<td></td>
<td>Topics include: Measurement, Properties of objects, Coordinate Geometry and Language of Geometry</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>“Algebra Foundations”</td>
<td>Algebra 2</td>
</tr>
<tr>
<td></td>
<td>Topics include: Algebra as a language, and Functions and Graphs through exponential and polynomial equations</td>
<td></td>
</tr>
</tbody>
</table>

These courses begin each daily lesson with a brief “Problem of the Day” activity. Students complete a mental math problem, explaining the solution or analyzing why a frequent multiple-choice answer is wrong. This activity is intended to build students’ self-confidence in addressing math problems by posing questions they can answer with their current skills and good reasoning they are likely to possess or to develop. This activity is also aimed at helping students check their answers for reasonableness and explain them by estimating simpler related problems.
The remainder of the period is an active hands-on lesson to develop skills and understanding of a core concept and skill, such as dividing fractions or using a coordinate space. Each lesson is a complete instructional package. It may include a whole class demonstration and discussion by the teacher; use manipulatives to explore conceptual foundations; student team discussions of alternative solutions to a problem with feedback to the class for team comparisons; or written reasoning and explanations for a math solution. A complete daily lesson package is provided that contains the rationale for the skill and concepts, a suggested time-line for each activity, overheads or models for use in the teacher-directed lesson, sets of manipulatives for students, and handouts to guide student discussions and reflections.

Evaluation studies show that this extra time with focused extra help approach in Talent Development high schools narrows the math skill gap for most students, increases the chances that all students will pass the required math courses, and significantly improves their test score performance over matched groups in traditional instructional programs (Kemple, Herlihy, & Smith, 2005; Balfanz, Legters, & Jordan, 2004). Other research on the use of transition courses shows their benefits for narrowing skill gaps (Gamoran, Porter & White, 1997).

**Content Literacy**

Strengthening all students’ abilities to read and understand the math and science textbooks is another important step to closing learning gaps (Barton, Heidema, & Jordes, 2000; D’Arcangelo, 2000). Students cannot benefit from the printed materials in their math and science classes when they are unable to read easily and understand the information. Indeed, some frustrated math and science teachers have discarded the assigned texts, taking the class time to verbally provide all the factual content, reducing instruction for deeper understanding.
The frequent call for more “content literacy” instruction in each subject has not yet produced approaches that are widely used and effective for teachers. Especially in the upper grades where teachers specialize in a single subject, there has been great reluctance to add reading instruction to other duties. Many teachers do not want to take class time away from their substantive material to help with student reading skills. Moreover, they do not feel equipped to teach reading in their subject, because math and science specialists have not had any training in teaching reading.

We are evaluating an approach to content literacy in middle and high school grades that uses interdisciplinary teams of teachers to work on three broad domains of reading in the different disciplines: text recognition, vocabulary, and comprehension strategies.

**Text format recognition:** Text format is the way a subject is usually presented in print, including how the text is arranged with subheadings, captions, sidebars, examples, and exercises, and how the content is ordered for thinking in the subject. Teachers in each discipline are already experts on text recognition in their field, even if they don’t recognize this strength. They are comfortable with the disciplinary thinking that is reflected in the text formats of their field, and familiar with how print is organized in their textbooks. With some training in the use of graphic organizers and skimming strategies, subject-matter teachers can help their students recognize text and establish reading expectations so that they can better handle printed materials in their course.

**Vocabulary:** Knowledge of new words or the precise usage of familiar words is another key to content literacy in math and science. Covering new words just before they are encountered in texts helps ensure that students can understand written material without getting bogged down in guessing or omitting words they don’t know. In mathematics, vocabulary lessons cover words that give directions, equivalent terms for mathematic operations and important linguistic
structures such as mathematical implication and naming (Treisman, 2006). Vocabulary in science can often be taught in word families built with different roots, prefixes and suffixes that are critical for deriving meaning from textual materials.

**Comprehension strategies:** Students will successfully comprehend when they use various strategies that prepare them with relevant background knowledge and reading goals, help them to think along with the author as they read and to check for their own understanding, and train them to summarize the main ideas in their own words. Teachers in each subject can help their students in these processes with some straightforward before-reading, during-reading, and after-reading activities.

Before-reading activities involve practicing new vocabulary to appear in the selection, and skimming the material for subsections, captions, and sidebar examples to establish an initial expectation of the content to be processed. Prior to reading, teachers can also assist by discussing the purpose for this reading, and any current knowledge or preconceptions about the reading topic.

During-reading strategies involve students recognizing the organization of thought such as cause and effect or chronology, being actively involved with the author by visualizing, questioning, or predicting, and monitoring for understanding with re-reading strategies when lost or confused. Teachers can help students develop these strategies by modeling reading processes with oral “read-aloud, think-aloud” presentations of related material where the teacher pauses at key points to verbally indicate the various active reading strategies.

After-reading strategies involve students putting main ideas or arguments in their own words, through student team discussions of the shared reading, students re-working their notes into possible test questions and answers, or students writing in their journals to reflect on what
they learned and how it may be useful. Teachers can facilitate these activities by scheduling student discussion time, feeding good questions to student teams for reflection and interpretation, and by following reading assignments with students writing on what was learned and developing pneumonics to recall key arguments.

**Teacher Teams for Content Literacy:** Many middle and high schools organize teachers in teams of four from the major disciplines (English, Math, Science, and Social Studies/History) who share the same students. These can be used very well for Content Literacy.

When teacher teams have common planning time to work together, they can establish a coordinated approach in content literacy. Under the leadership of the English teacher on the team, or with the assistance of a school reading specialist, all teachers can develop or use some simple parallel literacy activities in their classroom. The team can choose a “literacy skill of the week” so that the same literacy lesson is applied in each subject during a given week—such as text recognition, vocabulary development, or pre-reading strategies. Teachers can plan in teams to help one another with presentations, and students will receive consistent and coherent messages to assist their reading in each course.

The team structure can also facilitate various classroom management techniques for student reading. These include paired-reading where students read orally to each other, pacing of text coverage where key sections are covered at a slower rate for understanding, and independent reading as homework followed by paired reading in class for reinforcement.

Using interdisciplinary teacher teams with assistance from a reading specialist is a new way to help students develop content literacy through a few basic approaches of text recognition, vocabulary development and before-, during-, and after-reading strategies. The team structure can build on teachers’ thinking skills in their subject that are the foundation of text organization,
and support each teacher in shared classroom activities for content literacy. We are implementing and evaluating the team approach to content literacy in our network of Talent Development middle and high schools.

B. Attracting Under-represented Groups

Because women and some minority groups are significantly under-represented in math and science careers, K–12 education needs programs that interest these groups and prepare them in these fields.

The previous section offered some approaches for closing the skill gaps that prevent many minority students from entering college majors in math, science or engineering. But the absence of role models and traditional employment for women and minorities in high-level math, science and engineering careers also perpetuate the under-representation. Nevertheless, elementary and secondary schools can intervene to introduce all groups to a broad range of careers and to make the study of math and science more attractive to all students.

Female students often shy away from advanced work in math and science because it doesn’t connect to the traditional careers and college majors where women have been well represented. How can elementary and secondary schools broaden the range of careers that female and minority students seriously consider for themselves? How can they make the relevance of math and science courses more evident for every career that individuals prefer so advanced skills are developed for any later shifts to non-traditional careers in science and engineering?

The integration of academic and career education across the grades is being recommended to increase student motivation for serious learning and to broaden the outcome goals of schools, but it may also be a key to breaking down sex and race segregation across
occupational categories. Career factors can be introduced in the late elementary grades, with career awareness activities that expose all students to the full range of occupations and the skills and education needed for different jobs within broad career categories. At the high school grades, career preferences can be a major organizing factor for a student’s program of studies, when schools are reorganized into Career Academies and have instruction that blends interesting career applications in the major academic subjects.

**Career exploration in the middle grades**

The middle grades is a good point to introduce students to the broad categories of careers open to them, so that they can learn at an early age of role models from their own gender and race-ethnic group in all career groups and can think broadly about their own personal strengths and interests for different opportunities.

Career exploration curriculum materials have been developed for middle grades classrooms that expose students to the full range of careers and indicate the kinds of personal skills and interest that bring success in different fields. Students will learn that careers can be grouped in a few clusters for particular talents and interests, with many jobs within each set requiring different levels of education.* This orientation to broad occupational groups and associated talents can open the eyes of all young students to careers where women and minorities may have been traditionally under-represented.

This career awareness curriculum had been widely used in the Johns Hopkins Talent Development Middle Schools during weekly guidance periods. But the recent emphasis on test

---

* There are three popular broad categorizations for careers. The U.S. Department of Labor uses four dimensions: “Data” for careers using scientific or financial information; “People” for careers helping or leading others; “Things” for careers building or fixing products; and “Ideas” for creating or explaining something new. These four are overlapped with the six-level typology of Holland Codes that is organized around a hexagon for distance between categories: Realistic, Investigative, Artistic, Social, Enterprising, and Conventional (RIASEC). The U.S. Department of Education has a 32-category grouping that combines industry and career types.
preparation for core academic subjects has largely squeezed these units out of middle grades education. Including career knowledge in state assessment packages or returning an emphasis on career awareness in the middle grades would be valuable for integrating academic and career education and raising student interest in non-traditional occupations for their background group.

**Career focus for high schools**

Career Academies, a growing organizational approach for high schools, make serious study of math and science more relevant for students from every race-ethnic and gender group. The Johns Hopkins University Talent Development High Schools model features Career Academies and demonstrates the possibilities for more equity in pre-college math and science preparations.

Talent Development High Schools have multiple Career Academies that each enroll about 300 students across grades 10 through 12. Each academy offers a college-preparatory academic program, but with applications and elective courses around different career themes. The ninth grade is a separate unit. Students choose which academy they will join in the upper grades, after going through extensive explorations of their own interests and goals, as well as of the academy options at their school.

Academies bring coherence to each student’s program of studies, designed around personal interests, to develop strengths that will contribute to career success and satisfaction beyond the required academic skills. Students who make an informed choice of their academy are expected to be more motivated to attend school regularly and work hard because their program makes sense to them and relates to their goals and interests.

All ninth-grade students will participate in extensive career awareness exploration activities over a 6-week period in their first-term Freshman Seminar class. Students will learn
that careers can be categorized in a few broad groups that offer different satisfactions and require
different kinds of talents.

A high school will develop its own set of academy themes based on existing departmental
strengths and local labor markets. Each school is urged to have a variety of themes that cover
different career categories.

**Blended instruction**

Another way to increase motivation for math courses is to regularly show practical real-
world applications. This is sometimes called blended instruction because the core academic
courses in math incorporate interesting career applications to give context to instruction.

To be meaningful to students, blended instruction must go far beyond the short word
problems in many algebra texts. Blended instruction should have rich applications that challenge
student reasoning in the proper use of math formulations and tools. Such lessons are hard to find,
so Talent Development has written more than 60 examples for algebra classes to match different
academy themes. These lessons will be described in one of the afternoon sessions at this
conference.

Even in academies that are not primarily focused on science or engineering careers, the
blended algebra lessons will allow other students to see the relevance of math to their own
occupational preferences. With better appreciation of the need to study math, all students will be
developing core skills and understandings if they decide later to enter math or science fields.

### 4. Accountability

States and districts have established accountability systems to encourage schools to be
more responsible for teaching all students to high standards in core subjects, including math and
science. These accountability systems set standards by specifying the required number of courses and amount of instruction in core subjects and what topics and skills should be covered. The state accountability systems also establish the tests to determine how well students have learned. The high stakes consequences being phased in by different states can include denial of course credit, promotion, or graduation for failing students and staff changes or other outside interventions for schools with high failure rates. The close alignment of high standards, assessment measures, and classroom instruction is expected to bring student learning to higher levels.

Few would deny the need for a clear accountability system that provides public data on how well different student groups and schools are meeting learning standards and that establishes incentives for students and schools to work hard to reach high standards (Fuhrman & Elmore, 2004). At the same time, the dangers of unintended negative consequences exist if accountability systems are not well structured.

The first danger is that low state standards or narrow state tests will restrict classroom instruction. Some critics of state standards find weak coverage of advanced topics in math or science, due to lack of involvement of higher education faculty in their development or other reasons (Klein, et al. 2005). Others believe that the content of high stakes tests is the most powerful influence on classroom instruction, regardless of the published state standards content which may not be nearly as well known by teachers. Studies have shown that political pressures about failing too many students can result in the narrowing of test content or lowering of achievement cut points, or that social forces from poorly prepared students can restrict the topics covered in required courses (Ellwin, Glass, & Smith, 1998; McPartland & Schneider, 1996;
Wilson & Gretchen, 1993). In the end, the low floor of restricted course content and narrow tests can easily become the ceiling of what’s actually taught.

The most complete tests cover the required content domains and include both multiple-choice questions (“selected response items”) and written, open-ended questions where students can show their thinking or explain their answers (“brief constructed response items”). But the technical requirements for reliable, quick turn-around test scoring can discourage written answers to measure deeper understanding. When the required tests have a narrow format and focus on computation or recall, studies have shown that instructional time can be dominated for long periods by low-level test preparation of repeated exercises with short answer practice items (Herman, 2004; Lewis, 2006).

The second danger is that the consequences of test failure will be counterproductive to improvements by students or schools. For example, schools striving to reach a minimum required percent of passing students may concentrate only on those who are close to passing and largely ignore those who are so far behind the cut point that their improvements are not as strategically worthwhile. Schools may hold some low-performing students back in grade or exclude others from testing so that they don’t count at critical testing points. Also, in the grades where science tests are not required, science instruction can take a back seat.

Finally, there is also a “fairness” factor in the use of state tests. Students can suffer the dire consequences of grade retentions when their school is more to blame for ineffective instruction than the students for lack of effort. Or students who do not “test well” may fail, even though they can show in different ways that they actually have learned the material. Moreover, failing students may have to repeat the entire course, when they need to relearn only segments of the content. Similarly, schools that enroll every poorly prepared student from high-poverty areas
may make significant progress in narrowing gaps with most of their learners, but still fail to have enough students pass a fixed proficiency mark to avoid stark consequences.

We will deal here primarily with the issues of how accountability systems can have more positive impacts on classroom instruction in math and science. Two practical issues stand out for tracking accountability systems into a more positive force for excellent math and science education: how to revise test preparation instruction, and how to broaden the assessment package without more testing.

A. Good teaching as the best test preparation

Is it possible that the typical short-answer tests are not the real problem in narrowing classroom instruction, but a widespread misunderstanding of the best test preparation is to blame?

Narrow tests may not be a problem if the best test preparation can be conclusively shown to be good teaching of both basic skills and deeper understandings. Districts and schools would broaden their classroom instruction if they believed that student scores on standardized short answer tests will rise most when students learn both computational skills and conceptual understanding with the reasoning strategies to check their answers.

It makes sense that gains in computational skills go hand-in-hand with growth of conceptual understandings, and that one strength complements the other. Many students make mistakes in computation because they incorrectly apply concepts from another math unit and do not have good reasoning strategies to check their answers. For example, students make mistakes when working with fractions when they apply the number counting sense of whole number arithmetic instead of thinking conceptually of the multiples and ratios that underlie rational
numbers. Students who also can set reasonable boundaries for a correct answer by estimating simpler conceptually-related problems will be able to avoid multiple choice answers that do not make sense.

Some evaluation research shows that students do just as well on average with computations when they are taught with curriculum that emphasizes conceptual understandings, rather than only traditional skill-and-drill curriculum (McTighe, 2003). They also do significantly better on assessments of math reasoning and problem-solving (Shoenfeld, 2006).

We predict that good teaching of computational skills and conceptual understandings along with some limited practice with actual test items will result in significantly higher average test scores on typical multiple-choice tests. Experimental studies could actually calibrate the balance and timing of teaching for understanding and practicing computation items that works best.

If it turns out that even standard multiple choice tests require good teaching of both skills and concepts and that influential educational practitioners believe such evidence, the worries about accountability systems narrowing instruction may give way to more widespread balanced classrooms. But multiple studies must now be supported and conducted to clearly identify the instructional mixes that are the best test preparations for different assessments.

**B. Expanding the assessment package**

There can be many advantages to redesigning accountability practices by expanding the assessment package beyond a single high-stakes test from the state education agency. This may be especially true if other influential assessment components are located at the district and school levels. Several different kinds of assessments should be combined into a more complete and fair accountability package. These assessments include:
(a.) **State tests of student learning**

Every state uses standardized student achievement tests to meet federal requirements under the No Child Left Behind (NCLB) legislation, and to fulfill state regulations for promotion and graduation. In the early grades, these annuals tests cover English and math at particular grade levels. In the upper grades, the tests can either be end-of-course exams for specific subjects, or a comprehensive exam in math, English and other disciplines. Each test can use multiple choice questions or short written responses on a combination. The states can either use one of widely available published series, such as Terra Nova or SAT9, or develop their own to match the state standards and curriculum guides. Different consequences for students will result from their performance depending upon each state’s policies. These consequences include denial of grade promotion or graduation.

Some state tests have been strongly criticized for low standards and restricted content. A team of mathematicians reviewed the published math standards from every state and found all but three states to be deficient in the math content prescribed for elementary, middle and high school grades that connect to the state assessments (Klein, et al., 2003). They find most standards underemphasize conceptual understanding and computational skills of fractions in late elementary and each middle grades with not enough attention to paper-and-pencil calculations, and call for greater emphasis in the upper grades on completing the square of quadratic polynomials and applications to graphs of conic sections. They are also concerned that students will not develop computational skills and understanding of whole number arithmetic in the early elementary grades because of the excessive use of technology, manipulables, and discovery methods before sufficient practice with standard algorithms and memorization of basic number operations. They do not see the study of Algebra to be a natural progression over the grades as an
extension of arithmetic and use of integers and rational numbers. Although each state test was not examined by these critics these same deficiencies of state standards often transfers to state tests, where the appropriate prerequisite skills to be covered at each grade may not be covered, and the student use of calculators during testing may be inappropriate to their goals.

Another criticism of state tests has been their reliance on multiple choice or short answer items that emphasize factual recall and use of standard calculation algorithms. Such tests may miss the reasoning and problem-solving activities that get closer to students’ understanding of core concepts and ideas.

(b.) State tests for evaluating schools

Accountability systems usually also seek to evaluate individual schools with various possible consequences for low-performing units.

Tests can be used in several ways to evaluate schools. The percentage of students in each grade who exceed a designated proficiency level can determine a school’s standing. But because student achievement levels may reflect the student background and starting points, other calculations to isolate the effects of each school’s program are often included. The determination of the “value added” by the school program to student achievement may be estimated by the gains or progress made over a school year, compared to previous years at the same school, perhaps with statistical controls on student background factors in a general school productivity function. Sometimes, establishing several cut points of different proficiency levels can be used to compare changes in a school’s student performance distributions from the previous years.

One of the most novel and interesting approaches for evaluating schools occurred in Maryland which attempted to use various in-depth assessment components. Maryland developed an accountability system that used a variety of assessment tasks to evaluate how well students
could use knowledge and understanding to work on complex problems. The goal was to provide incentives for schools to teach to these higher-order goals. These assessment tasks not only used essays and other lengthy response formats where student could demonstrate their reasoning, but also used complex projects where teams of students worked together to find solutions. Each assessment segment took extensive time to complete, so several days were set aside for these assessments. Another novel feature of this system was a multi-matrix sampling arrangement where not every student participated in each assessment segment but subgroups within each school were randomly assigned to subsets of the assessment task battery, so many different assessments tasks were covered in every school.

This Maryland system put priority on evaluating schools for their learning outcomes by combining the performances of the different student subgroups across the various assessment tasks and arriving at a school score. Individual student scores could only be calculated by a complicated scoring system that identified the difficulty level of each task and weighted individual student performances accordingly.

While this Maryland accountability system went far beyond most others in creating multiple assessment formats to examine a wide range of what students know and can do in core subjects, it was eventually replaced with more conventional paper and pencil tests for individual students, where schools are rated by the percent of students who pass designated proficiency points. The more ambitious accountability system was dropped because of the time it took to administer and score, disagreements about moving instruction toward the assessment tasks, and the priority for uncomplicated individual student achievement scores that could be aggregated for school evaluations, rather than the other way around.
(c.) Local district or departmental exams

Assessments are being made all the time for determining report card grades and deciding who passes the courses. Usually, these are teacher-made exams determined by the individual instructors and administered in their classes. But sometimes all teachers in a subject area at a school will get together to write the items for a term or course exam, or to use examination questions provided by their school district as part of their final grade.

Local district or departmental exams could be included in an overall assessment package, especially if their scoring is not done by the instructor but by other teachers in their department or district. Such tests have the power of external exams where students know they cannot pressure their teachers to be lenient and where scoring has some neutral credibility.

Local exams can use more challenging formats, such as complex problem-solving with written student accounts of their reasoning and checking behaviors, because the local teachers can complete timely scoring and coordinate the assessments with their instruction as feedback and learning experiences.

(d.) Portfolios of student work

Teachers commonly use evaluations of student work as a component of a course grade. Term papers, products from long-term projects, and written homework or class work assignments can be marked and weighted in calculating a final grade. Even oral demonstrations can be scored and used for grading.

The advantages of incorporating student work into the evaluation process are the integration of instruction and grading and the opportunities to use different modes for students to show what they have learned and what can do with it.
At least one state (Kentucky) has used portfolios of student work in its assessment package.

**Accountability systems with multiple assessments**

Rather than relying on a single high-stakes state test to determine student fates or to intervene with schools, a broader accountability package could be used for better educational results. Local district or school assessments should be incorporated with state tests to broaden the package and avoid more testing unconnected to the usual grading practices. The local assessments may include existing district tests, existing departmental exams in each school or student demonstrations or portfolios now used in grading. Or, districts could be charged with developing and justifying new local assessment components, which would be passed upon by state authorities. Careful procedures will be needed to be sure the local components cover core standards and the scoring is unbiased. Perhaps, large pools of assessment questions or problems provided or approved by state officials could bring sufficient standardization, and anonymous local scoring by teachers of others’ classes or sample monitoring of teacher ratings could ensure sufficient objectivity. A weighting formula should be established so that all state and local accountability components are taken seriously for student grades and promotion decisions, and instruction will be balanced to cover both specific skills and broad understandings to be covered across the assessment package.

Though many others have called for a broader accountability package, we are still far from a system that uses both state and local components as incentives for good instruction, appropriate student decisions, and helpful school directions. But other actions to improve math and science instruction may be impeded until the accountability systems make more sense.
5. Summary

The solutions most frequently heard to upgrade pre-college math and science instruction through adding more teachers and using better tests may be helpful, but do not deal well with the current realities of poorly prepared current teachers, unmotivated students, and narrow accountability systems. We may add 70,000 more math and science teachers and require tests of higher standards and still be left with typical classroom instruction that is unbalanced toward skills without understanding. Teachers may know no other way; many students may continue to find math and science to be boring, irrelevant or out-of-reach; and required tests may still get in the way of good instruction.

This presentation has considered how the social organization of schools might be modified to (1) upgrade classroom instruction by re-deploying the current math and science teaching staff and supporting them with more complete lessons and more regular coaching, (2) increase student motivation across all groups for math and science by providing extra time and focused extra help with content literacy instruction for needy students and by integrating career and academic instruction for different student interests, and (3) broader accountability systems with assessment packages of state and local evaluations that cover a range of student outcomes as incentives for excellent instructions in mathematics and science.
References


