Better

Evidence-based Education

MATH

Effective strategies for building students' math skills

For better math outcomes, focus on the classroom

Steven Ross and Deborah Lowther on technology in education

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Editorial

WELCOME to the second issue of *Better*, which focuses on mathematics.

Everyone agrees that math is a critical subject for all school children. But how can teachers best ensure that all students reach their full potential? Although there is a good deal of evidence on what works (and what doesn't) in elementary, middle, and high schools, it is not always easy to find this information.

This magazine is intended to give educators access to research on a particular subject. The last edition focused on reading, and so it seemed appropriate that this time the focus should be on math. We are very pleased to have contributions from some of the world's leading researchers on the subject, and we hope that their articles will not only prove interesting to you, but also help you make informed decisions.

Better was created by the Institute for Effective Education at the University of York, and by the Center for Research and Reform in Education at the Johns Hopkins University. We are delighted that the first edition of the magazine received very positive feedback, and we hope you will feel the same way about this one. Of course, if you have any comments please do let us know!

Robert Slavin
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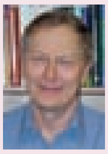

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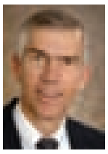

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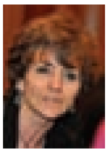

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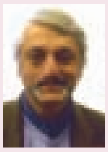

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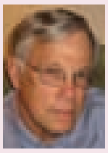

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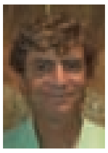

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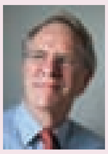

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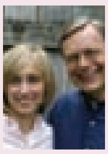

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VOLUME 2, ISSUE 1

What works in teaching math

For better outcomes, focus on the classroom, not just the curriculum, writes Robert Slavin

IF STUDENTS are to reach their full potential, they must be able to confidently compute and solve complex math problems. To ensure success in math for all children, educators need to know which programs and practices are effective. Which textbooks, computer programs, and professional development strategies increase math achievement?

We carried out a review of research on math programs in both elementary and middle/high schools. The aim was to place all types of programs on a common scale. In this way, we hope to provide educators with meaningful, unbiased information that they can use to choose programs and practices. We examined the quantitative evidence on math programs to discover how much of a scientific basis there is for competing claims about their effects.

Our review threw some interesting light on the kinds of math reforms that are likely to improve the achievement of children in math.

Studies we included

In order to be included in our review, studies had to meet a number of common-sense criteria:

- Students participating in a program had to be compared to children using ordinary methods;
- Students participating in a program had to be well-matched to those using ordinary methods;
- Measures had to be fair to all groups (and not, for example, be a test inherent to the program); and
- Programs had to be evaluated for at least 12 weeks, and preferably a year or more.

> “There is no evidence that different curricula give different achievement outcomes. Clearly this has enormous implications for teaching and policy”

We considered studies carried out in all countries, but the results had to be available in English. The majority of studies were done in the U.S. In total, nearly 200 studies met the inclusion criteria for the two reviews. They broke down into three broad areas – math curricula, computer-assisted instruction (CAI) approaches, and teaching strategies.

Math curricula

A number of studies measured impact on achievement for various textbooks and curricular innovations. These fell into three categories:

- Innovative strategies that focus on problem-solving, alternative solutions, and conceptual understanding;
- Traditional commercial textbooks; and
- A back-to-basics textbook that emphasizes a step-by-step approach.

There were 13 studies of elementary curricula, and 40 of middle/high school curricula. There was very little evidence that it mattered which curriculum was used. None of them showed any strong evidence of effectiveness in comparison to the others. Although it might be suggested that the standardized tests used to measure performance would not detect some of the more sophisticated skills taught by some innovative curricula, there didn't seem to be any evidence of this in the studies we looked at.

CAI approaches

In elementary schools, technology has typically been used as a supplement to classroom teaching, often used only a few times a week. These programs can help to identify children's strengths and weaknesses and then give them self-instructional exercises designed to fill in gaps.

Across the 38 elementary school studies that qualified for our review, we found that most studies found positive effects, and none significantly favored a control group. However, there was not enough high-quality evidence to recommend one program over

another. We also found that the outcomes were stronger for computations than for concepts or problem solving. This is not surprising, as CAI particularly helps children with their computation skills.

In middle/high schools, technology is used in three ways in the teaching of math:

- Supplemental programs, used to fill gaps in children's knowledge;
- Core programs, where the computer largely replaces the teacher; and
- Computer-managed learning systems that use a computer to assess students and provide teachers with feedback for use in lessons.

In the 40 qualifying studies that looked at these various programs, there was little evidence of effectiveness. No program stood out as having large and replicated effects.

Professional development

A number of studies have looked at the impact of using extensive professional development to help teachers use effective teaching strategies. These studies usually keep the textbooks, content, and objectives the same, but change the teaching methods.

There were 36 qualifying studies of professional development strategies in elementary schools and 22 in middle/high schools. Professional development programs had the strongest evidence of effectiveness. Cooperative learning was particularly strong. In cooperative learning students work in pairs or small groups to help each other. This strategy increases learning if the groups have a common goal that they can only achieve if all group members do well on independent learning. In other words, students have to teach each other, because their own success depends on it.

In elementary schools, programs that focused on classroom management and motivation also had strong evidence of effectiveness.

Conclusions

There are a number of important conclusions to be taken from our reviews:

- There is no evidence that different curricula give different achievement outcomes. Clearly this has enormous implications for teaching and policy;
- There is also limited evidence that ordinary CAI improves math learning; and
- Finally, there is strong evidence that using effective teaching strategies can make a real difference. Changing the way that children work together, and classroom management and motivation, can improve the math outcomes for all students.

The full reviews, together with educator's summaries, can be found on the Best Evidence Encyclopedia, **www.bestevidence.org**

About the author

Robert Slavin is director of the Institute for Effective Education at the University of York and the Center for Research and Reform in Education at the Johns Hopkins University. He is also Chairman of the Success for All Foundation, a restructuring program that helps schools to identify and implement strategies to meet the needs of all learners.

What we know

- No evidence that different curricula give different outcomes.
- Limited evidence that ordinary CAI improves learning.
- Strong evidence that using effective teaching strategies can make a difference.

Further reading

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The importance of the early years

Research provides findings – some surprising – about the importance of math for young children. Douglas Clements and Julie Sarama explore these, and suggest ways to build up children's mathematical concepts and skills

NEARLY A CENTURY AGO two giants of psychology gave quite different impressions of the role of math in the lives and education of young children.

It seems probable that little is gained by using any of the child's time for arithmetic before grade 2, though there are many arithmetic facts that he [sic] can learn in grade 1.

Edward L Thorndike, 1922

Children have their own preschool arithmetic, which only myopic psychologists could ignore.

Lev Vygotsky, 1935

Throughout history, views of the role mathematics should play in young children's lives have differed widely. However, recent research has revealed striking findings of its importance and role in education.

Young children need to learn math

The early years are an especially important period for learning math. Children's knowledge of math in the pre-school and early elementary years predicts their mathematics achievement for years later – throughout their school career. Moreover, what they know in math also predicts their reading achievement later. Their early knowledge of literacy also predicts their later reading ability – but only reading ability. Given that early math predicts later math *and* reading, it appears that math is a core component of cognition. Learning math is therefore important. This is especially true for children from deprived communities, who often have not been provided with rich opportunities to build math ideas and skills.

Young children can learn challenging math

Even infants can discriminate between groups of two objects and only one object. There is no age too young for mathematical thought. Older children often know more than curriculum developers or teachers believe. Even among those who have not had many advantages, most children starting school can count, recognize some shapes, make patterns, and use non-standard units of measurement.

Young children often know, and can definitely learn, far more challenging and interesting mathematics than they are taught in most classrooms. Preschoolers often see little or no math, and students in the early

Developmental Progression	Instructional Tasks
Counter (Small Numbers) Accurately counts objects in a line to 5 and answers the "how many" question with the last number counted. When objects are visible, and especially with small numbers, begins to understand cardinality. "1, 2, 3, 4... four!"	**Cubes in the Box:** A child counts a small set of cubes. Put them in the box and close the lid. Then ask the child how many cubes you are hiding. Tip them out and count together to check. **Road Race Counting Game:** Students identify number amounts (from one to five) on a dot frame and move forward a corresponding number of spaces on a game board.
Counter and Producer (10+) Counts and counts out objects accurately to 10, then beyond. Keeps track of objects that have and have not been counted. Counts a scattered group of 19 chips, keeping track by moving each one as they are counted.	**Counting Tower:** Allow children to count to 20 and beyond. Ask them to make towers with objects such as coins. Children should build a tower as high as they can, placing more coins, but not straightening coins already in the tower. The goal is to estimate and then count to find out how many coins are in your tallest tower. To count higher, have children make pattern "walls." They build a pattern block wall as long as they can. This allows them to count to higher numbers.

Figure 1: Examples of Selected Levels from the Building Blocks Learning Trajectory – see more examples at **www.betterevidence.org**

years of elementary school engage in math far less than they do in literacy. Furthermore, too many curricula and programs for young children "teach" too much of what they already know. There are examples of good practice, but we can and must do better. High-quality early education results in learning benefits throughout elementary school, especially for children from disadvantaged communities.

Learning trajectories: The secret of success

Educators generally agree that teachers should "start where the child is" and "differentiate teaching." But how? Research has provided a powerful tool: learning trajectories. Students follow natural developmental paths in learning mathematics. When teachers understand these, and sequence activities based on them, they build learning environments that are developmentally appropriate and effective. Learning trajectories have three parts:

- **Goals:** The big ideas. Goals should include the big ideas of mathematics – clusters of concepts and skills that are mathematically central and coherent, consistent with children's thinking, and generative of future learning. For example, counting and how to solve problems using counting.
- **Development progressions:** The paths of learning. The developmental progression is a typical path children follow to achieve their goal. Our learning trajectories provide simple labels and examples for each level of each developmental progression, and this is shown in Figure 1. The first column describes two main levels of thinking in the counting learning trajectory (there are many more before, in between, and after).
- **Instructional tasks:** The paths of teaching. The final part consists of a set of tasks, matched to each of the levels of thinking in the developmental progression. These tasks are designed to help children learn the ideas and skills needed to achieve that level of thinking. That is, teachers can use these tasks to promote students' growth from one level to the next. The second column in Figure 1 provides example tasks.

Benefits of learning trajectories

Thus, learning trajectories describe the goals of learning, the thinking and learning processes of children at various levels, and the learning activities in which they might engage. Several "gold standard" randomized control trial studies have shown that curricula and professional development based on learning trajectories increase children's achievement more than those that do not.

> "Educators generally agree that teachers should 'start where the child is' and 'differentiate teaching.' But how?"

A teacher participating in one of these studies observed one student had almost filled her pretend pizzas with toppings in the task she was working on. As she got ready to roll the number cube, she said, "I'm going to get a high number and win!" "You can't," replied her friend, "You have four spaces and the number cube only has ones, twos, and threes on it." The teacher reported, "The numbers may be small, but the reasoning was impressive!" Such thinking is one reason why math is a core component of cognition.

What we know

- Learning math at an early age is critically important for young children, especially those from disadvantaged communities.
- Educators often underestimate what young children know and can learn about mathematics.
- Using research-based learning trajectories is effective in promoting math learning.

About the authors

Douglas H Clements is SUNY Distinguished Professor and **Julie Sarama** Associate Professor of Learning and Instruction at the University at Buffalo, State University of New York. They conduct research on young children's learning of math, geometry education, and the scale-up of scientifically-based curricula and intervention models.

Author note

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Building mathematics skills

Chris Kyriacou **draws on recent research to identify the key features underpinning effective strategies for building students' mathematics skills**

THE DEVELOPMENT OF STUDENTS' SKILLS in mathematics during their school years has been subject to a wealth of research. Moreover, the political importance for governments in fostering high achievement in mathematics is evident in most countries around the world. As such, taking stock of what research can tell us about effective practices for building students' mathematics skills is a key area of both political and educational interest. In 2003, a Mathematics Education Review Group was established at the University of York by Maria Goulding and myself, funded by the UK Department for Education and Skills (now: Department for Children, Schools and Families). The group comprises researchers and teacher educators from eight universities, together with some representative teachers, local authority advisers, and policy makers. The group has carried out four systematic reviews of relevant literature focusing on key aspects of the teaching and learning of mathematics in primary and secondary schools in England (the equivalent of elementary and middle/high schools in the U.S.). The full report of these reviews can be found on the Evidence for Policy and Practice Information and Co-ordinating (EPPI) Centre website: www.eppi.ioe.ac.uk.

The first of our reviews looked at the effectiveness of the teaching strategies underpinning the UK's National Numeracy Strategy, which was introduced into primary schools in England in 1999. In particular, we focused on the use of whole class teaching in the context of the "daily mathematics lesson" for students aged 5–7 years. The second review focused on the effectiveness of strategies for enhancing the motivation of "lower-achieving" students aged 14–16 years. The third review looked at the use of computer-assisted instruction (CAI) to teach algebra in primary and secondary schools. Finally, our fourth review looked at the use of teacher–student dialogue in mathematics lessons to enhance mathematical understanding for students aged 7–14 years. Taken as a whole, there are a number of evidence-based practices that can be advocated, and these are highlighted here in terms of three key themes.

> **"One of the main barriers to success in developing mathematics skills lies in a student's belief that 'math is not for them – it's for the clever ones'"**

Inclusiveness

Perhaps the most powerful theme that has emerged from these reviews is the importance of classroom practices that promote a sense of inclusiveness. One of the main barriers to success in developing mathematics skills lies in a student's belief that "math is not for them – it's for the clever ones." It is thus extremely important for teachers to ensure that all students are able to experience a sense of progress and success in the mathematics they are doing. An important aspect of this is the use of differentiated tasks, so that students can engage with mathematics in a way that is appropriate for their ability and level of prior understanding, and that they receive support and encouragement when needed. Inclusiveness also requires teachers to make use of strategies where the share of contribution each student in a class makes to discussion is equal and equally-valued by the teacher. Small group work tasks can enhance students' engagement in mathematical activities by providing a safer (less exposed) learning context within which to share ideas and also by fostering a greater awareness of metacognitive strategies (how students think about, direct and evaluate their thinking while engaged in a problem-solving task) through observing and discussing with peers how to approach a problem. Such strategies can have a powerful effect on enhancing students' self-identity as someone who can do mathematics.

Deep thinking

An important aspect of coming to see oneself as a student who can succeed in mathematics, is to be able to undertake tasks that are challenging but "achievable with effort." A danger with mathematics teaching is that sometimes, in order to avoid students experiencing failure, a teacher will adopt a comfort zone around their work, so that students may not feel sufficiently challenged or stretched by the work they do. Our reviews, however, indicate that a powerful influence on how students develop a positive self-identity as learners of mathematics comes from experiences in which they are challenged to think harder and deeper about the mathematics they are doing. The insight they then develop in the context of this effort enables them to feel they can succeed, and to also get a sense of the enjoyment that comes from problem solving, which generates a deeper understanding of the mathematics they are doing. One particular aspect of this involves the use of CAI. At one level, the use of CAI by the teacher and students can act as a powerful motivator, but there is a danger that too much teaching and learning involving CAI can be superficial in terms of the depth of mathematical understanding being fostered. It is only when CAI is linked to the promotion of deeper learning that the real benefits of using CAI as a vehicle through which mathematics skills can be fostered are genuinely realized.

Ownership

In many classes, the teacher is viewed as the expert, and learning is seen by students as a matter of paying close attention to what the teacher says and does before trying some exercises for oneself. Ownership refers to the ways in which teachers make use of strategies where students can take greater

control over the direction of the lesson. One example of this concerns how teachers can create a learning environment in which teacher–student and student–student dialogue is used to convey that students' views are taken seriously, and are allowed to influence which approaches to problem-solving are explored and the interpretation of mathematical understandings that result. An effective strategy here is to go beyond the use of a teacher–student dialogue comprising a simple sequence of initiation–response–feedback (i.e. the teacher asks a question, the student gives an answer, the teacher comments on the answer) to enrich the dialogue by asking more challenging questions, asking students to explain their answers, and involving other students in a more extended sequence. The term co-construction has become more frequently used to describe how teachers can adopt a more equal role with students in how they generate and consider different approaches to solving mathematical problems and evaluate these together.

What we know

- Students need confidence in their ability and self-identity as learners of math.
- Strategies that promote inclusiveness, deep thinking, and ownership have a powerful effect.
- High-quality professional learning activities are needed to support teachers.

Conclusion

In order to become capable and strategic learners in mathematics, students need to have confidence in their own ability and self-identity as learners of mathematics. Strategies that promote inclusiveness, deep thinking, and ownership, can have a powerful effect on building students' mathematics skills. This can be contrasted with those strategies which can be characterized as viewing learning in mathematics as elitist (only for clever students), superficial (the application of well rehearsed procedures), and teacher-centered (follow what the teacher says and does). All four of our reviews have also pointed to the need for high quality professional learning activities to enable teachers of mathematics to make use of evidence-based strategies.

About the author

Chris Kyriacou is Reader in Educational Psychology at the University of York Department of Educational Studies, and co-director of the UK DCSF-funded Mathematics Education Review Group. He is also the author of two very popular textbooks on teaching: *Effective Teaching in Schools* and *Essential Teaching Skills*.

Further reading

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Which instructional methods are most effective for math?

James Hiebert and Douglas Grouws reveal which elements of math instruction have been shown to help students' conceptual understanding and their skill efficiency

DECIDING WHICH INSTRUCTIONAL METHODS are most effective for increasing students' learning continues to be one of the great challenges for educational research. Should teachers use Method A or Method B? Which one will show the best results?

An important truth about the effectiveness of instructional methods is that particular methods are not, in general, effective or ineffective. Instructional methods are effective for something. Educators always need to be clear about what this something is when they talk about the effectiveness of instructional methods.

Focusing on the following two learning goals, we ask which instructional methods are most effective: conceptual understanding – the construction of meaningful relationships among mathematical facts, procedures, and ideas; and skill efficiency – the rapid, smooth, and accurate execution of mathematical procedures. These two learning goals are central to mathematics learning and have often competed for attention.

Conceptual understanding

Research conducted over the past 75 years has spanned a wide range of mathematics topics, age groups, and class settings. The results point to two important features of teaching that can help the development of students' mathematical understanding.

Work and talk

Teachers and students should intentionally and explicitly talk about, and work on, important mathematical relationships.

At least some time during each lesson should be spent on the following activities:

- Examining relationships among facts, procedures, and ideas within a lesson and across lessons. Is one problem a special case of the preceding problem? How the problems solved today are similar to and different from the problems considered yesterday? How do linear graphs, tables of ordered pairs, and linear equations all represent the same linear function?
- Exploring the reasons why procedures work as they do. In addition to practicing procedures, students should examine and discuss why the procedures work, especially when new procedures are being introduced. Why do we usually add from right to left? When we solve an equation,

why must we do the same thing to both sides? and

- Lessons frequently involve solving problems using different procedures and then examining the similarities and differences between them. How is Jack's procedure different from Martha's procedure? Note: It is not necessary for students to practice multiple procedures for solving similar kinds of problems, but comparing different procedures is beneficial.

Work and wrestle

Teachers should provide opportunities for students to wrestle with key mathematical ideas and ensure that students do some of the important mathematical work in the lesson.

Allowing students to work hard to make sense of mathematics does not mean standing by while they become unnecessarily frustrated and confused, nor does it mean presenting problems that are well beyond their reach. But it does mean providing time during the lesson when students are allowed to work on problems they don't immediately know how to solve, and it does mean resisting the temptation to jump in and tell students how to do something at the first sign of uncertainty.

At least some time during each math lesson, teachers should engage in the following activities:

- Pose mathematics problems to students that are just beyond what they currently know how to handle. Useful problems are those for which students have many of the prerequisite skills but that require something more or different.
- Ask students to present their solution strategies for a challenging problem and engage the class in examining the mathematical validity of the strategies.

It is well known that understanding develops as people try to resolve perplexities or dilemmas that cannot be immediately sorted out. Wrestling with perplexing situations often results in rethinking ideas and creating new and better explanations for how things work.

Skill efficiency

How can effective instruction help students develop efficiency in executing mathematical procedures? Patterns in the results of research point to a constellation of instructional features that facilitate the development of students' skill efficiency:

- Classes should be well organized, fast paced, and focused on mathematics;
- Teachers should set the speed, organize the lesson, and present material;
- The teacher's modeling of new material must be clear and concise; and
- Once students are ready to succeed, significant time should be allotted for error-free practice.

Lessons should progress from the teacher's presentation and the modeling of mathematical material to practice time for students. During the modeling part of the lesson, the teacher presents material clearly and in a meaningful, organized way. The teacher also asks questions throughout this part of the lesson. These questions are mostly product questions requiring students to provide only answers and are asked publicly for the entire class to hear. The transition from the whole-group portion of the lesson to individual student practice occurs only after the students are well prepared. The fast pace of the lesson keeps students' attention while ensuring that students move from one task to another successfully. Lessons are content-focused, so that class time is devoted to mathematical tasks as opposed to managerial tasks, such as handing back papers or discipline.

Not a simple correspondence

The apparent disparity between one set of instructional features for conceptual understanding and a completely different set of features for skill efficiency, breaks down when examining the results of studies on conceptual understanding that also report a significant increase in students' skills. Apparently, it is not the case that only one set of instructional features facilitates conceptual learning and another set facilitates skill efficiency. Two quite different kinds of features both appear to promote skill learning.

Perhaps the nature of skill learning is somewhat different under the two instructional approaches. The measures used to distinguish different kinds of skill competencies have not been sensitive enough to confirm this. But we can say that instructional methods are likely to facilitate more than one kind of learning. So, when choosing methods it is wise to consider the full set of learning goals that are valued. If both conceptual understanding and skill efficiency are desired, the evidence would recommend using the instructional features for conceptual understanding, or using a balance between the two approaches.

Old dichotomies are not helpful

A number of categories have been frequently used to contrast methods of teaching, such as didactic versus discovery, direct instruction versus inquiry-based teaching, student-centered versus teacher-centered teaching, and traditional versus reform-based teaching. Although these categories and labels might have been useful for some purposes in the past, the instructional features that facilitate conceptual understanding and skill efficiency do not fall neatly into these categories. They no longer capture the distinctions suggested by the data. Attending explicitly to key mathematical relationships, for example, can be done within any of these methods.

These findings suggest a weighted balance between the two instructional approaches might be appropriate, with a heavier emphasis on the features related to conceptual understanding.

What we know

- To improve conceptual understanding, make explicit the important mathematical relationships and ask students to "work and wrestle."
- To improve skill efficiency, use rapid pacing, modeling, and moving to error-free practice.
- Balance these two approaches, with a heavier emphasis on conceptual understanding.

About the authors

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Douglas A Grouws is Research Professor and William T Kemper Fellow at the University of Missouri where he works with doctoral students and conducts research. His research focuses on mathematics teaching and curriculum evaluation.

Further reading

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Understanding mathematics learning

Learning math is not as easy as 1, 2, 3, but is influenced by some quite surprising factors. Celia Hoyles **explains more**

ALL STUDENTS LEARN MATHEMATICS in school, but what and how they actually learn is influenced in part by factors beyond the curriculum and even beyond the way in which lessons are delivered. Students may be taught procedures to support calculation, yet these can be learned without a real grasp of why they work as they do. Furthermore, progress in math can be subject to wider influences. For example, although students prefer to tackle math with a common-sense approach, they often forego this for an approach which they believe is more likely to gain approval. Teachers need to be aware of the fragility of students' appreciation of mathematical argument, and encourage reasoning rather than "answer getting."

Seeing through numbers

Along with two colleagues, Lulu Healy and Dietmar Küchemann, I conducted two large-scale studies of students' views of math in England between 1995 and 2003. These studies explored how high-achieving students (in the top third) justified mathematical conjectures, judged mathematical arguments, and explained their reasons. Both studies compared findings at different levels (students/classes/schools) to interpret students' conceptions and progress with reference to the landscape of school and teacher factors.

In the first study, 2,459 high-achieving students aged 15 years from 94 classes in 90 schools completed two proof questionnaires (one for algebra and one for geometry) while their teachers completed a teacher/school questionnaire.[1] The second study adopted a similar approach but added a longitudinal dimension, analyzing the development of mathematical reasoning for students from age 12 to 14 years.[2] Thus, 1,512 students from 54 randomly selected schools completed a proof questionnaire.

We asked similar questions each year. In some, students had to justify conjectures and present arguments to gain the best marks. One question asked annually in the second study was a number/algebra task involving a tile pattern, quite familiar to English students. The version for students aged 14 years (see Figure 1) consisted of two parts, A1a and A1b. The students were given one example of the relationship showing 6 grey tiles and 18 white tiles; in part a, they had to generalize this to another number (60) of white tiles and explain their numerical calculation. In part b, students were asked to write a general relationship involving n white tiles. The version for students aged 12 years consisted only of part a, as most students of that age have not experienced much algebra. The aim of the task was to discover whether students would generalize on the basis of structure or use spurious number patterns arguing, for example, that 6 white tiles had 18 grey tiles round them, so for 60 you multiply the 18 by 10 to give 180.

Despite some improvement between students aged 12 years and students aged 13 years, a substantial minority continued to use "number pattern spotting" strategies which gave the incorrect solution of 180 grey tiles. Altogether, 35% of students aged 12 years gave such responses. Although this fell to 21% for students aged 13 years, it stayed at 21% for students aged 14 years. Interestingly, longitudinal data show that it was not the same students who always made pattern-spotting responses: rather, of those giving such a response in any one year, only about half repeated that response in subsequent years. Students in fact flipped between pattern spotting and structural reasoning, indicating that mathematics learning is neither stable nor linear – a sobering reflection for teachers of mathematics.

Face-to-face interviews and data analysis confirmed this fragility of students' appreciation of mathematical argument. It suggests that teachers need to work on scaffolding students' structural perspective as well as on reinforcing recognition when students "get it."

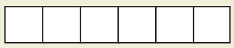
Figure 1: Number Patterns or by Mathematical Structure

A1

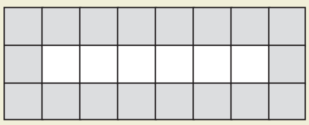
Lisa has some white square tiles and some grey square tiles.

They are all the same size.

She makes a row of white tiles.



She surrounds the white tiles by a single layer of grey tiles.



(a) How many grey tiles does she need to surround a row of 60 white tiles? ....

Show how you obtained your answer.

(b) Write an expression for the number of grey tiles needed to surround a row of *n* white tiles. ....

Figure 2

Arthur, Bonnie, Ceri, Duncan, Eric and Yvonne were trying to prove whether the following statement is true or false:

When you add any 2 even numbers, your answer is always even.

Arthur's answer

a is any whole number
b is any whole number
$2a$ and $2b$ are any two even numbers
$2a + 2b = 2(a + b)$

So Arthur says it's true.

Bonnie's answer

2 + 2 = 4	4 + 2 = 6
2 + 4 = 6	4 + 4 = 8
2 + 6 = 8	4 + 6 = 10

So Bonnie says it's true.

Ceri's answer

Even numbers are numbers that can be divided by 2. When you add numbers with a common factor, 2 in this case, the answer will have the same common factor.

So Ceri says it's true.

Duncan's answer

Even numbers end in 0, 2, 4, 6, or 8. When you add any two of these the answer will still end in 0, 2, 4, 6, or 8.

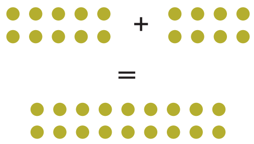
So Duncan says it's true.

Eric's answer

Let x = any whole number,
y = any whole number
$x + y = z$
$z - x = y$
$z - y = x$
$z + z - (x + y) = x + y = 2z$

So Eric says it's true.

Yvonne's answer



So Yvonne says it's true

From the above answers, choose one that would be closest to what you would do if you were asked to answer this question.

From the above answers, choose the one to which your teacher would give the best mark.

The influence of audience: Seeking approval

All our student proof questionnaires included multiple-choice questions presenting mathematical conjectures with several supporting arguments. Students were asked to make two selections from these arguments: the argument nearest to their own approach and the argument which they believed would receive the best mark from their teacher (see Figure 2).

Fascinatingly, both surveys (like findings elsewhere) found that students held two different conceptions of a mathematical argument simultaneously: those arguments which they considered would receive the best mark and those which they would adopt themselves. When they were trying to please the teacher, arguments using letters (to students, a strong signal for algebra) were popular – despite their sometimes making no sense (41% of students thought Eric's argument would receive the best mark). For themselves, students preferred arguments that they could evaluate using common sense. This preference tended to exclude algebra (the most popular answer, which 29% of students chose, was Duncan's).

These choices provide startling evidence of the disconnect between the justifications chosen by students for themselves and those they considered suitable for the teacher's approval. We listened to what the students themselves said. We found that algebra was deemed appropriate in proofs for the teacher, but largely because it makes the answer seem so complicated, while other forms were judged perfectly adequate for the students themselves.

Challenging classes

Student responses to proof questionnaires were susceptible to the wider influences framing effective teaching. For students aged 14-15 years, the percentage of children in the class entered for higher-tier GCSE (General Certificate of Secondary Education: an academic qualification awarded in UK schools) had a statistically significant effect on student proof scores: the higher the percentage of higher-tier students in the class, the better the class proof score. Reasons may include the motivating effect of "real" mathematics: more curriculum time, higher expectations of the students, and more challenging questioning.

Questions for teachers

If students see algebraic proof as a ticket to the best marks, they have not understood its mathematical significance. How can teachers detach the language of algebra from "letters to please the teacher" and help students grasp it as a tool for expressing their own ideas and arguments in increasingly rigorous and unambiguous ways?

Since students find it difficult to link their own informal and narrative arguments with deductive arguments in algebraic symbolism, can teachers find ways to scaffold these connections?

How can teachers build on learners' pre-existing knowledge to encourage reasoning rather than "answer getting"?

About the author

Celia Hoyles OBE is Professor of Mathematics Education at the Institute of Education, University of London. She has directed more than 30 research and consultancy projects concerned with mathematics, and published widely in articles and books. From 2004–2007 Professor Hoyles was the UK Government's Chief Adviser for Mathematics.

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Further reading

On-line panel discussion on proof www.ncetm.org.uk/proofdiscussion.

Online community for teachers www.ncetm.org.uk/proofcommunity.

Principles for effective teaching of mathematics www.ncetm.org.uk/mathematicsmatters.

Depth Of Knowledge for mathematics

Norman Webb **explains why the teaching of math should be aligned with the complexity of the subject**

TEACHERS ARE FACED with a vast array of guidance regarding what students should know and should be able to do. Teachers use textbooks and planning guides, national organizations make recommendations, and researchers disclose greater insights into the learning sequence and process. Teachers need to make sense of how their own methods fit, and align their teaching with these expectations, so that students learn what they are expected to know and do. But how can they do this?

Content complexity

"Content complexity" is a theory that has been discussed by academics since the late 1940s and is one technique that teachers can use to ensure that their teaching is aligned with learning expectations and assessments. Content complexity differentiates learning expectations and outcomes by considering the mental processing of concepts and skills in particular prior knowledge and the number of steps that need to be considered to complete a task. In mathematics, content complexity is related to a student performing a set procedure or recalling information, applying a multiple step process or conceptual understanding, or solving a non-routine problem where several approaches are possible.

Depth Of Knowledge

Depth Of Knowledge (DOK) is a language system used to describe different levels of complexity. Four levels specify the degree of complexity of mathematical content, as it relates to typical students at a given age. These are:

Level 1 (*Recall*) includes the recall of information such as a fact, definition, term, or a simple procedure, as well as performing a simple algorithm or applying a formula. Generally in mathematics a one-step, well-defined, and straight algorithmic procedure should be included at this basic level. At secondary level, solving a system of two equations with two unknowns generally requires a set procedure for eliminating one variable and solving for the second variable. Because students are expected to apply a standard procedure, finding the values of the two variables is a DOK level 1.

Level 2 (*Skill/Concept*) includes the engagement of some mental processing beyond a habitual response. A Level 2 assessment task requires students to make some decisions as to how to approach the problem or activity. Level 2 expectations and activities imply more than one step. Action verbs, such as "explain," "describe," or "interpret" could be classified at different levels depending on the object of the action. For example, interpreting information from a simple graph – reading information from the graph by considering the units on the axes and other attributes – is a Level 2. Level 2 activities are not limited to just number skills, but can involve visualization skills and probability skills. Other Level 2 activities include: extending non-trivial patterns, explaining the purpose and use of experimental procedures; carrying out experimental procedures; making observations and collecting data; classifying, organizing, and comparing data; and organizing and displaying data in tables, graphs, and charts.

Level 3 (*Strategic Thinking*) requires reasoning, planning, using evidence, and a higher level of thinking than the previous two levels. In most instances, requiring students to explain and justify their thinking mathematically is a Level 3 task. Activities that require students to make conjectures are also at this level. The cognitive demands at Level 3 are more abstract than at Levels 1 or 2. The complexity does not result from the fact that there are multiple answers, a possibility for both Levels 1 and 2, but because the task requires more demanding reasoning. Other Level 3 activities include drawing conclusions from observations; citing evidence and developing a logical argument for concepts; explaining phenomena in terms of concepts; using concepts to solve problems; and critiquing experimental designs.

"Frequently, content complexity is interpreted as content difficulty. Difficulty can be related to complexity, but what makes a mathematical activity hard for a student depends on more factors than just how complex the activity is"

Level 4 (*Extended Thinking*) requires deep reasoning, planning, developing, and thinking activities over an extended period of time. At Level 4, the cognitive demands of the task should be high and the work should require drawing upon multiple resources or analyses. Students should be required to make several connections – relate ideas within the content area or among content areas – and have to select one approach among many alternatives on how the situation should be solved, in order to be at this level. Level 4 activities include developing and proving conjectures, designing and conducting experiments, making connections between a finding and related concepts and other phenomena, and combining and synthesizing ideas into new concepts. Conducting a research project including developing the questions, creating the design, collecting and analyzing data, drawing conclusions, and reporting the results would be a typical Level 4 activity.

Frequently, content complexity is interpreted as content difficulty. Difficulty can be related to complexity, but what makes a mathematical activity hard for a student depends on more factors than just how complex the activity is. If a student has not had the opportunity to learn a

concept or skill, applying the concept or skill will probably be difficult. Also, applying a repetitive action, such as memorizing and recalling a large number of digits of π, can be difficult to achieve, but is still just recall of information and is therefore a DOK Level 1 task.

Case study

In one school district in the U.S., a mathematics coordinator used DOK to help teachers understand the inconsistency between students' grades and their scores on the state assessment. Most students in the districts were receiving high grades in mathematics. However, their scores on the state assessment were below proficiency. Teachers used the DOK levels to analyze the complexity of the state standards and assessments, and compared this to the complexity of the teaching methods they used. Teachers found that most of their techniques focused on DOK Level 1 activities (recall of information) whereas the state standards expected students to have a conceptual understanding of the main ideas (a DOK Level 2) and some solving of non-routine problems (a DOK level 3).

Conclusion

Attention to content complexity is important for ensuring that instruction is aligned with expectations. Depth Of Knowledge is one means for defining content complexity. A number of considerations are necessary to assign a DOK level to instructional activities, expectations, or assessment activities. Among these are the actions, the subject of the actions, prior experience, and mathematical sophistication. Awareness of content complexity through the use of DOK levels helps to ensure that students will learn mathematics as fully expressed in high expectations and assessments.

About the author

Norman L Webb is an emeritus research scientist at the Wisconsin Center for Education Research at the University of Wisconsin–Madison. He is currently a visiting research scientist for the National Science Foundation.

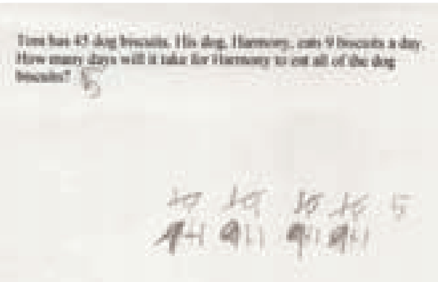
What we know

- Paying attention to content complexity is important. Depth Of Knowledge is one way of defining content complexity. There are four levels:
  Level 1 – Recall
  Level 2 – Skill/Concept
  Level 3 – Strategic Thinking
  Level 4 – Extended Thinking

Supporting sense making: Thinking mathematically

Students often have unique ways of solving problems, ways that can surprise adults. Megan Franke explains how teachers can use this knowledge to support math development

EVERY DAY, students bring intuitive knowledge and mathematical insight to school. By building on this informal knowledge, teachers can ensure that students learn with understanding. Consider how one second grader solved the following problem.



Harry solved the division problem 45÷9 = ____ by decomposing 45 into 4 tens and a five (10 + 10 + 10 + 10 + 5). He then changed the 10's to 9 + 1. He took out the 4 nines for 4 days of dog biscuits. He had 4 ones left and then along with the five, he made another group of 9. His answer was 5 days. Harry's solution often surprises adults. What is apparent is that he chose to use a strategy that made sense to him and used a basic property of number.

Cognitively Guided Instruction

For the last 25 years, a professional development approach called Cognitively Guided Instruction (CGI) has supported teachers to create classrooms in which students build on their existing mathematical knowledge so that they connect their new ideas to existing ones.[1] CGI focuses teachers on what students know, not what they do not know.

CGI provides teachers with knowledge about how students solve problems and how strategies develop with experience. It helps teachers to know what to listen for as they engage their students in explaining their mathematical thinking. Listening to students' mathematical thinking may sound easy, but students often do not solve problems in the same ways as adults. Teachers therefore need opportunities to learn how students will solve problems, and how then to support them in developing more efficient and mathematically sophisticated strategies.

Teachers often pose word problems that ask students to find the missing addend:
"Lily has 6 stickers.
How many more stickers does Lily need to earn so that she will have 13 stickers altogether?"

Adults typically expect students to solve this problem by subtracting 6 from 13. However, research shows that children naturally follow the action in the problem, and start by counting out 6 objects, and then add objects to those 6 until they have 13. They then count the objects they added to the 6 and find they need 7 more. Rather than seeing this as a subtraction situation, the students see it as an adding or joining situation, 6 + ___ = 13. If we teach students to subtract to solve this problem and the students think of it as a joining problem, we create a disconnect between students' existing ideas and the new mathematical idea. We create confusion rather than sense making.

Research also shows that the pattern of development in student strategies is robust and the strategies naturally build on one another. In the previous problem, students start with the strategy that follows the action in the problem, a strategy we call *direct modeling*. They then move to a counting strategy that also follows the action but does not involve making the initial group of 6. Here the student thinks 6 and says 7, 8, 9, 10, 11, 12, 13 counting on her fingers so she can look at her fingers and see that she needs 7 more stickers to get to 13. In solving addition and subtraction problems students typically begin by direct modeling, move to a counting strategy, then use derived facts (6 + 6 = 12, so 6 + 7 must be 13) and recall (I know that 6 + 7 = 13).

What is important is that we can document the development of children's mathematical thinking across a number of mathematical domains such as addition/subtraction, multiplication/division, place value, multi-digit calculation, and the development of algebraic thinking. CGI shares this research-based knowledge with teachers, who take this knowledge and use it to structure learning opportunities. We do not provide a curriculum or a set of practices that a teacher must use. The teachers use the knowledge in ways that make sense for them in their situations and within whatever curricula they use.

CGI leads teachers to consider how to:
- Choose and pose problems that support student learning;
- Allow students to solve problems in ways that make sense to them;
- Structure classrooms to allow students to share their thinking; and
- Probe student thinking.

> "Understanding the development of students' mathematical thinking within domains like addition and subtraction allows teachers to choose problems that students can begin to solve, and ones that challenge their thinking"

Choosing and posing problems to meet students' mathematical needs

Understanding the development of students' mathematical thinking within domains like addition and subtraction allows teachers to choose problems that challenge students' thinking. Teachers can also then choose problems that allow for multiple strategies and fit with where students are in the trajectory. They choose numbers that support student understanding. Engaging in sense-making around the problem opens up opportunities for students to participate because they understand the problem and what is being asked.

Allowing students to solve problems in ways that make sense to them

CGI research shows that it is critical to create an environment in which students can solve problems in a way that makes sense to them. This requires knowing that not all students will use the same strategies at the same time, and ensuring that students have the tools they need to solve the problem. Teachers need patience and knowledge of what strategies to expect and how to scaffold tasks to help students see what they do know.

Structuring classrooms for shared thinking

CGI teachers offer students opportunities to share their thinking. They create a set of norms and expectations that encourage students to explain their thinking as they learn mathematics. They do this by providing time for students to work together to solve problems and share solutions. Students are always asked how they worked a problem out, and the teacher listens to their misunderstandings as well as their understandings. They make sure that students explain their responses, and ask other students what they heard and if they understand. A teacher might ask: “Can anyone tell us what they think Anna is doing?” They might ask students to compare strategies, “In which of the strategies did the students start by combining the tens?” Sharing mathematical thinking allows students to learn from each other.

Probing students’ mathematical thinking

CGI teachers ask students not only, “How did you solve that?” but also specific follow-up questions, “Where did the ten come from?” in ways that lead students to detail their thinking. We know that supporting students to get complete and detailed explanations on the table is productive for their learning. This means that beyond the initial question the follow-up questions matter. Specific follow-up questions that are related to what the student said or did help students the most. Questions like, “I see you started counting at 9, can you tell me why you did that?” or “I see three tens there, what did you do with those?”

Conclusion

CGI researchers continue to study the development of students’ mathematical thinking, as well as how knowing about the development of student mathematical thinking shapes teachers’ practice and supports student learning. CGI research consistently demonstrates that teachers who know the details of their students’ mathematical thinking have higher achieving students.

About the author

Megan Franke is a professor at the Graduate School of Education and Information Studies, University of California, Los Angeles.

Reference

1. CGI is an elementary level mathematics professional development program developed at the University of Wisconsin, Madison by Elizabeth Fennema, Tom Carpenter, Megan Franke, Linda Levi, and Susan Empson along with a number of graduate students and teachers. The original research was conducted by Fennema, Carpenter & Peterson.

Further reading

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Bowland math: turning theory into practice

Quentin Thompson **outlines the Bowland math initiative which aims to help students develop (and teachers teach) math skills of thinking and problem solving**

"BRITAIN IS NOT GOOD ENOUGH AT MATH." This was the Bowland Trust's starting point for its math initiative. The first step was to establish the stage (between pre-kindergarden and post-doctoral) which was most critical in terms of developing the nation's mathematical abilities. The conclusion was clear: Key Stage 3 – the equivelant of middle school in the U.S. The first years in middle school math no longer makes intuitive sense. Helping all students to succeed at this point and to maintain positive attitudes towards math is particularly important.

Background

Much of the teaching of math for students aged 11-14 years tends to focus on "sums" – arithmetical or algebraic – equivalent perhaps to teaching grammar in English. In both cases, these building blocks are not what the subject is really about.

However, unlike in English, math teaching for students aged 11-14 years (and aged 15-16 years) rarely gets past these building blocks. Nevertheless, "Using and Applying," which covers some such broader aspects, has been part of the UK National Curriculum since 1988. These are arguably some of the most interesting aspects of math, so when they are not well taught – if at all, no wonder students find the subject boring: they see neither what it is for, nor, more importantly at that age, what fun it can be.

The aims of Bowland math

Bowland Math, an intiative supported by the Bowland Charitable Trust, aims to change students' attitudes about math and so improve their achievement. Motivation is all. An important second purpose is to change teachers' approach to teaching math. This requires: new curriculum materials; support for teachers with targeted professional development; and new types of assessment materials. These are the three foundations of the Bowland initiative.

> **"Using and applying are arguably some of the most interesting aspects of math, so when they are not well taught – if at all, no wonder students find the subject boring: they see neither what it is for, nor, more importantly at that age, what fun it can be"**

Curriculum materials

The curriculum materials are designed so that students see math in contexts that they find interesting and fun – they then see the math as part of that fun. Consistent with the conclusions in other articles in this issue of *Better* (e.g., Slavin, Kyriacou), Bowland developed a series of larger problems (called Case Studies), taking 3–5 lessons, which are "open," interactive, require students to think and discuss ideas, and tend not to have right or wrong answers. Most importantly, the problems are on topics that students of that age find interesting – not necessarily from the "real" world, but from fantasy worlds as well. Each Case Study requires using imagination, reasoning, making multiple links, and communicating. The excitement of the math is in seeing how it helps to makes sense of the problem and so help to solve it – sometimes as something of a surprise!

So far, there are 18 Case Studies, developed by a variety of organizations, each one trialed in several schools. They include:

- Exploring cost effective ways to reduce road accidents in a town;
- Investigating where hostile aliens have landed, finding a means of escape and then rescuing their teacher;
- Designing a new healthy "smoothie" fruit drink based on a survey of tastes
- Inter-galactic travel, trading various goods; and
- Examining ways to prevent the spread of a virus outbreak.

Three more Case Studies will be available shortly and a further half dozen or so around the end of 2010.

Professional development

To support teachers with the pedagogical challenges of "open" problem solving, Bowland developed five professional development modules, built around similar but smaller problems, designed and tested by a consortium of experts. The modules cover issues such as tackling unstructured problems, using questioning and reasoning, and managing collaborative work. Each can be used by teachers for self-study or working in groups.

As well as being on the web (www.bowlandmaths.org.uk), five DVDs containing all the materials have been distributed free to schools in England – with the assistance of the National Strategies (professional development programs provided by the UK Government). Some additional training has been provided via the UK Mathematical

What we know

- Process skills for students aged 11-14 years are important and can be taught
- Bowland materials help students to learn about thinking and problem solving
- This new style of learning is popular and effective with students and teachers

Association and the UK Association of Teachers of Mathematics, as well as being orchestrated by the UK National Centre for Excellence in the Teaching of Mathematics (NCETM).

Assessment materials

The third foundation comprises assessment materials, and scoring such assessments requires judgement. Bowland is currently developing about 40 such tasks, each to be presented with extensive examples of students' work. These should be available on the web early in 2010. A little later, there will be two further professional development modules specifically for assessing process skills.

Outcomes – so far

It is, of course, too soon to assess the impact on the original goals (of changing attitudes and so performance in math). Bowland is planning to survey usage late in 2009, which will start to consider impact. Meanwhile, there has been much individual (and positive) feedback on the materials (see, for example, the Bowland community on the NCETM website – www.ncetm.org.uk).

Student comments

Students clearly love the problems – many have told their teachers that they now think math is more fun and interesting and that they learned more this way. Quotes from students:

"I used to HATE math ....Doing this project has rose (sic) my confidence a lot and I would love to do another project using Bowland! I LOVE Math NOW. It's the best. I really wanted to be better at math and doing this has made me really happy about it."

"You get your brain thinking with all the sorts of problems and questions, which is good because then you improve your mathematical skills."

"We did more group work and got more work done."

"It was fun. I learned more than usual."

Teacher comments

Teachers also seem to enjoy the new approach – many saying that the rewards are well worth the preparation time:

"This new style of teaching is one I've been yearning for. The materials that Bowland have developed are fresh and exciting."

"Usually students' work starts with mathematics, in a context or otherwise. By contrast, in the Bowland case studies the students engaged with the contexts and then discovered that they needed to use mathematics to solve the problems."

"We were about to begin work on enlargement and I asked [my class] what they remembered about the previous work we had done on it [six months before] – around the same time as we did Outbreak. It was quite an effort dragging anything out of them... I then asked who remembered doing Outbreak. A sea of hands went up; they didn't just remember that it was special and fun, they were also able to talk about their use of angles and coordinates and working out percentages and bearings, which they had found hard, but tackled successfully because they were doing it for a reason. Using [Bowland's] Outbreak clearly had a positive effect both on their enjoyment and on their understanding of mathematics." [paraphrased]

So, while it is too soon to assess impact, early signs are very positive.

About the author

A math graduate from Cambridge, **Quentin Thompson** taught in schools, worked in government, and was a policy adviser in the Cabinet Office, UK. He subsequently headed, for 20 years, the education practice in a consultancy firm. He now advises the Bowland Trust on their math project.

Effectively using technology in education

Steven Ross and Deborah Lowther explore the value of technology in the classroom

OUR FIRST SIGHT of the aging inner-city school left us totally unprepared for what we observed inside. Students in every classroom were highly active and engaged; their voices intermixed with pervasive clicking of computer keyboards. The fifth and sixth grades were working on a "unit project" on Mexico, designed to integrate learning of history, geography, foreign language, and mathematics. Students gathered around laptops individually or in pairs performing a wide variety of technology applications, downloading Internet resources, creating spreadsheets and graphs, and designing PowerPoint presentations on project findings. When the bell rang, most had to be coaxed to stop working and go to their next class.

Is educational technology effective? This real-life scenario from our evaluation study of a technology integration program (Freedom to Learn) in Michigan clearly suggests that it can be. In this case, "effectiveness" meant improved higher-order learning and preparation for careers. But if effectiveness also means raising assessment scores, the verdict would have been less favorable. As we will show by examining three major application areas, educational technology is not a single approach but a broad range of modalities, tools, and strategies for learning. Its effectiveness, therefore, depends on how well it helps teachers and students achieve desired goals.

Technology as a tutor

The most enduring and well-researched application of educational technology is computer-assisted instruction (CAI). Modern CAI programs provide tutorial lessons and "drill-and-practice" exercises adapted to students' needs, with graphics and animation that make them more engaging and interesting than textbooks. However, research shows that students learning from CAI programs generally perform about the same as those receiving conventional, teacher-led instruction. But should such results be interpreted to mean that CAI programs are ineffective? As Richard Clark argued several decades ago in criticizing "media comparison" research, what impacts on learning is not how a lesson is delivered but what teaching strategies are employed. Although effective CAI programs use many evidence-based strategies (e.g., adaptive content, frequent testing, immediate feedback, etc), so do effective teachers. CAI, therefore, seems most valuable as a supplement rather than replacement for teachers. Some valuable uses include:

- Giving students practice on key skills and content while freeing the teacher to tutor others or perform other tasks;
- Providing remedial instruction for low-achieving students;
- Providing enrichment activities for students who successfully complete a regular lesson;
- Providing supplemental teaching when teachers can't be available (after school or in the summer); and
- Teaching material in a different way to yield deeper levels of learning or to assist those who failed to learn it the first time.

Technology as a teaching aid

Another valuable role of technology is increasing teachers' effectiveness in organizing and presenting class lessons. For example, the Reading Reels program, developed by the Success for All Foundation, embeds strategically selected video segments in daily first grade reading lessons. Humorous animations, puppet, and live-action sketches illustrate key letter sounds, sound blending, and vocabulary. Children chant along with the characters, or compete with them to supply the right sound or word. Not surprisingly, several rigorous studies have shown that the addition of this modest enhancement (about 5 minutes in a 90-minute lesson) significantly increased reading outcomes.

Multimedia presentations extend teachers' abilities to make material more meaningful and engaging. But the more options teachers have for improving lesson quality, the greater the demands for organizing or "orchestrating" many diverse teaching activities. Interactive whiteboards have shown great promise in recent British studies as a compelling solution to the orchestration problem. Among the valuable features for improving lesson quality are:

- Active and interactive learning: Teachers or students can write on the whiteboard, and manipulate content;
- Lesson organization is improved: All lesson elements can be loaded into the computer and projected on the whiteboard (e.g., PowerPoints, video, images, letters, words, etc);
- Valuable lesson orchestration is embedded directly in the teaching: Lesson outlines can indicate at what point alternative teaching activities (e.g., lecture vs. cooperative learning) should be used; and
- Teaching is highly adaptable to needs and interests: Teachers can modify the lessons, if desired, using vast digital resources available.

Numerous other technology-based teaching aids are making their way into today's classrooms. For example, by using Interactive Classroom Communication Systems (known

as clickers), students immediately respond to questions posed by the teacher. The answers are instantly aggregated and graphically displayed. Benefits include:

- Timely feedback for teachers about student learning;
- Valuable review and feedback for students; and
- "Community-centered" learning with high student interactivity.

Technology as a learning tool

The school described in the opening scenario illustrated students learning, not so much about or from computers, but with computers to solve problems and produce meaningful work. Unfortunately, even after three decades of technology initiatives in the UK and the U.S., this level of integration of technology with classroom learning remains more the exception than the rule. For example, a recent report from the U.S. Department of Commerce ranked education as the least technology-intensive enterprise among 55 U.S. industry sectors. Just as sobering, a recent survey of over 400 U. S. employers revealed that high school graduates are entering today's workforce deficient in most of the 21st Century knowledge and skills needed to achieve successful careers. Viewed from this perspective, proficiency *in using technology* for such contemporary tasks as searching the Internet, creating graphs and illustrations, and communicating through multimedia presentations has become an *essential* educational outcome, much like being proficient in reading and mathematics. Unfortunately, research shows that schools serving disadvantaged students are more likely than wealthier schools to use computers for "drill-and-practice" functions than as a meaningful learning tool. Thus, the socioeconomic gap is widening in this important domain.

In a series of recent quasi-experimental studies, we and our colleagues examined efforts by multiple school districts to integrate computers as a learning tool. What we found in the "computer-intensive" settings were:

- More frequent student-centered, cooperative, and higher-order learning;
- Superior student writing, problem solving, and 21st-century technology skills;
- Extremely positive attitudes by students, parents, teachers, and school leaders; and
- Higher quality, more sustainable technology integration programs when initial professional development was combined with ongoing in-school peer coaching.

Also noteworthy is what we did not find – achievement advantages on state assessments. While there would be every reason to believe that the positive teaching and climate changes observed will benefit virtually all types of learning, such "far transfer" effects are likely to take time.

Conclusions

For the last four decades, researchers have given extensive attention to comparing the effectiveness of computers and teachers in improving test scores. Given the essential goal of preparing today's students for higher education and careers, we encourage shifting emphasis to a different research focus – how to use technology reflectively and scientifically to make teachers and curricula more effective. Three forms of technology applications, all showing considerable promise for this purpose, are as a tutor, as a teaching aide, and as a learning tool. The first two forms augment and enhance what teachers can do on their own to orchestrate and adapt teaching to individual needs. The latter form is directed to enabling students in all ethnic and socioeconomic groups to use technology effectively to master and perform 21st-century skills.

About the authors

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Further reading

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Washington corner:

Changing view of silver bullet solutions

WASHINGTON HAS LONG BEEN IN SEARCH of the "silver bullet" for education, breathlessly promoting the latest and greatest new idea. Extended day. Extended year. Pay for performance. Pay for grades. Tenure reform. Afterschool programs. Teacher mentoring. School choice. Differentiated accountability. Growth models.

While these methods have the potential to have a positive impact on student learning, choosing just one or choosing several unsystematically will never reform education. We have not been able to find the silver bullet because it is a myth. Silver bullets worked for the Lone Ranger, but he lived only in fiction.

In particular, no one has invented or will ever invent a silver bullet solution for the struggling schools that serve high-poverty neighborhoods. Such schools can indeed turn themselves around and can achieve remarkable gains, but not by rushing after the latest fad or adopting a patchwork approach. Research-based turnaround models that use a multifaceted, comprehensive approach to school reform offer far more promise than the latest "hot idea." Such models focus on the core of practice-curriculum, instruction, classroom management, assessment grouping, accommodations for struggling students, parent involvement, and more.

School reform that addresses all aspects of school functioning is not easy. It is not cheap. But it works.

Evolving Resources, More Choices

In 2002, when No Child Left Behind was first signed into law, the choices of comprehensive strategies proven by research were slim. Schools face a different picture today. Multiple resources are now available to make an informed decision among research-based reforms broadly available to schools that need them.

Many programs have been identified as effective by a number of major research clearinghouses that conduct systematic reviews to identify effective programs. These include the Best Evidence Encyclopedia, the What Works Clearinghouse, the Comprehensive School Reform Quality Center, and Social Programs That Work.

Each of these clearinghouses comes to somewhat different conclusions, as each has a somewhat different process. However, one thing they all have in common is that they all empirically identify the programs most likely to generate positive outcomes from a field of seemingly good ideas.

"School reform that addresses all aspects of school functioning is not easy. It is not cheap. But it works"

The availability of this growing set of resources means there are more proven choices available for school leaders. These options allow schools to choose a reform model that is not only proven effective, but also fits their specific needs.

A Changing Federal Landscape

The unique thing about the comprehensive programs identified as effective by these clearinghouses is that they are the successful integration of multiple strategies, not a single silver bullet. The U.S. Department of Education and state departments of education should encourage the adoption of programs proven to be effective. There is more money on the line than ever before. Competitive grant processes that encourage the adoption of proven programs will provide the greatest yield for each dollar invested.

Local school districts and school leaders do not need to wait for a federal or state consensus. They can make the choice now to implement a program that has a demonstrated track record of success. Some local officials may experience "sticker shock" over the cost of implementing a research-proven comprehensive school improvement strategy. This reaction is understandable, not just because of the current economic climate, but because of the proliferation of bargain-priced programs that have no research base. Local officials should look back and consider how much they spent on dubious "good idea" programs that failed to produce meaningful results for their students.

Secretary of Education Arne Duncan has been rolling out an ambitious agenda for reform, along with unprecedented resources behind the effort. It is his goal to turn around the lowest-achieving 5,000 schools in the country in the next five years. He calls this reform effort "education's moonshot," and discourages "flash-in-the pan" solutions, which fail to offer sustainable school improvement. In some ways, Duncan's agenda is even more ambitious than a moonshot. He is calling upon education leaders to change the way they think, act, and spend within our current education system. And he wants it to happen fast.

Duncan and his Washington team are working hard to release guidance for several structured funds that intend to spur reform. The largest effort to be led by reform minded states is the Race to the Top Fund (RttT), funded at $4.35 billion dollars. RttT will only go to a limited number of states, but this is not the only new funding opportunity for reform-minded local leaders. School Improvement Grants (SIG) are funded at an unprecedented $3 billion and will be awarded to States to make subgrants to local education agencies. While guidance is not finalized, this fund is designed to strongly encourage comprehensive turnaround strategies. Finally, the Investing in Innovation fund (i3) will offer $650 million to local education agencies that partner with non-profit organizations in scaling up evidence-based practices that improve student outcomes.

Duncan's call to action makes comprehensive turnaround strategies more necessary than ever. Comprehensive, proven strategies are the only way to guarantee large scale results in a short time period. Duncan's plan does emphasize the expansion of charter schools and other new schools, an initiative that will take time to come to fruition. Comprehensive reform models are ready to go, and will work in whatever schools are prepared to adopt them--both charter schools and traditional public schools.

Becoming an Agent of Change

Arne Duncan cannot reform education on his own. He is depending on thousands of state and local education leaders to serve as agents of change.

No one is under the illusion that these changes will be easy. It is all too easy to use the latest buzz words but maintain the status quo, but doing so deprives students of their potential for future success. True agents of change in a school or district are often met with resistance. Education leaders must step away from the latest popular trend, and make the bold decisions that are required to achieve long term, sustainable reform.

Several organizations that offer comprehensive, research-based turnaround models also offer support to school leaders striving to implement bold reforms. With the Department of Education behind the effort as well, the momentum today is stronger than ever before. This is the perfect moment for cultivating bold reforms. For once, Washington is supporting the use of what works, rather than advocating for the elusive silver bullet. Educators need to embrace this opportunity by working to improve all aspects of teaching and school organization, which will add up to real and lasting turnaround.

"Arne Duncan cannot reform education on his own. He is depending on thousands of state and local education leaders to serve as agents of change"

Useful Resources for Identifying Reform Models

Best Evidence Encyclopedia
www.bestevidence.org
The Best Evidence Encyclopedia (BEE) is produced by the Johns Hopkins University. It is intended to give educators and researchers fair and useful information about the strength of the evidence supporting a variety of programs available for students in grades K-12.
Reviews Include:
Beginning reading
Upper-elementary reading
Middle/high school reading
Struggling readers
English language learners
Early childhood education
Elementary math
Middle/high school math
Financial incentives
Comprehensive school reform

What Works Clearinghouse
ies.ed.gov/ncee/wwc
The What Works Clearinghouse (WWC) was established by the U.S. Department of Education's Institute of Education Sciences to promote informed education decision making. The WWC website provides educators with databases and reports that review the effectiveness of replicable educational interventions intended to improve student outcomes.
Reviews Include:
Beginning reading
Elementary math
Middle school math
Early childhood education
English language learners
Dropout prevention
Character education

Comprehensive School Reform Quality Center
www.csrq.org
The Comprehensive School Reform Quality Center (CSRQ), which operated from 2003 through 2006, was established through a grant to the American Institutes for Research from the Office of Elementary and Secondary Education of the U.S. Department of Education. The CSRQ website provides an extensive series of consumer-friendly reviews and supplemental guidance on the effectiveness and quality of comprehensive school reform (CSR) models.
Reviews Include:
Elementary school CSR models
Middle and high school CSR models
Education service providers

Social Programs That Work
www.evidencebasedprograms.org
The Social Programs That Work website was developed by the Coalition for Evidence-Based Policy, whose mission is to promote government policy making based on rigorous evidence of program effectiveness. The site provides policy makers and practitioners with clear, actionable information on what works, as demonstrated in scientifically-valid studies.
Topics Include:
Education
Youth development
Crime/violence prevention
Mental health
Substance abuse prevention
Employment
Welfare

One-to-one tutoring identified as gold standard among interventions for struggling readers

JOHNS HOPKINS UNIVERSITY'S Center for Research and Reform in Education (CRRE) recently conducted a systematic review of programs for struggling readers. According to the review's findings, one-to-one tutoring by certified teachers and reading specialists is the "gold standard" among interventions for low-achieving students.

> "One-to-one tutoring is highly effective in improving the reading performance of low-achieving students"

As part of the review process, CRRE looked at hundreds of studies evaluating the effectiveness of various interventions for struggling readers. A total of 96 studies met the review's rigorous inclusion standards. The types of programs reviewed included one-to-one tutoring by teachers, one-to-one tutoring by paraprofessionals and volunteers, small group tutorials, classroom instructional process approaches, and instructional technology.

After a thorough review of the research, CRRE concluded that one-to-one tutoring is highly effective in improving the reading performance of low-achieving students and that an emphasis on phonics greatly improves tutoring outcomes. Classroom instructional process programs, especially cooperative learning, were also found to have positive effects. In particular, tutoring in first grade, followed by cooperative learning throughout the elementary grades, was shown to have the best long-term outcomes for struggling readers. Traditional instructional technology programs, which use computer-assisted instruction software, were shown to have little impact on low-achieving students.

Taken together, the key findings of this review support a strong focus on improving classroom instruction followed by targeted, phonetic tutoring for students who continue to experience difficulties.

Center for Research and Reform in Education, 2009

Leadership academy for principals linked to increased student achievement

ACCORDING TO A STUDY from New York University's Institute for Education and Social Policy, graduates of New York City's Aspiring Principals Program (APP) – a pre-service principal training program – have helped increase student achievement in some of the city's most challenging schools.

The study, which is the first independent examination of APP's effectiveness, systematically compared student outcomes in schools led by APP graduates to student outcomes in comparable schools led by traditionally trained new principals. All principals in the study were installed in 2004-05 or 2005-06, remained in the same school for three or more consecutive years, and led their school through the 2007-08 school year. During those years, student test scores were collected and benchmarked against city-wide assessment data.

Findings of the study showed that, for English Language Arts, graduates of APP helped increase student test scores in elementary and middle schools at a faster pace than other new principals. APP graduates also helped increase math scores, but at a pace no better than their non-APP trained counterparts.

Created in 2003 by New York City's Leadership Academy, APP is a 14-month leadership development program that uses teamwork, simulated-school projects, and job-embedded learning opportunities to prepare participants to lead instructional improvement efforts. In particular, participants are primed to manage schools marked by high student poverty and low achievement.

Institute for Education and Social Policy, 2009

U.S. Department of Education study uncovers trends in educational technology

THE ENHANCING EDUCATION THROUGH TECHNOLOGY (EETT) PROGRAM is a federally funded technology initiative with three main goals: 1) improve student academic achievement through the use of educational technology, 2) ensure that every student is technologically literate by the eighth grade, and 3) encourage the effective integration of technology in teacher training and curriculum development.

In an effort to examine the implementation of the EETT program, the U.S. Department of Education conducted a study that analyzed educational technology trends in schools. Their report provides descriptive information about educational technology practices related to the core goals and strategies of the EETT program. Data for the study was collected from nationally representative samples of states, districts, and teachers between school years 2002-03 and 2006-07. A total of 27 case studies were included in the study.

The results of the study showed that student access to the Internet was similar across high-poverty and low-poverty schools, according to teacher survey responses. Similarly, computer access, with the exception of laptops, was nearly equivalent. Teacher surveys responses also suggested that there was a statistically significant increase from 2004–05 to 2006–07 in the number of teachers reporting several types of technology use to support their own work on a weekly basis. However, teacher reports did not reflect any increase in the frequency of student technology use for learning.

With respect to teachers' technology proficiency, states were generally not collecting data regarding the percentage of teachers meeting state technology standards. States also lacked consistent, reliable data regarding the percentage of students meeting state technology literacy standards by eighth grade.

U.S. Department of Education, 2009

High quality teachers found to have positive impact on peers

STUDENTS HAVE LARGER TEST SCORE GAINS when their teachers engage in peer learning with high quality colleagues, according to a study from the National Bureau of Economic Research.

The study, which reviewed longitudinal data on North Carolina school children from 1995 through 2006, tested whether or not changes in a teacher's peers affect the test score growth of his or her own students. A focus was placed on math and reading test scores of students in the 3rd through 5th grades.

Using two separate measures of peer quality – one based on observable teacher qualifications and the other on estimated peer effectiveness – the study concluded that teachers perform better when the quality of their peers improves within the same school over time. In particular, *changes* in the quality of a teacher's colleagues were associated with *changes* in his or her students' test scores gains.

This study provides some of the first documented evidence of the effects of a teacher's peers on his or her own effectiveness.

National Bureau of Economic Research, 2009

Plateau effect in test scores may not be cause for concern

IN EDUCATION, the "plateau effect" describes the perceived phenomenon that test scores rise in the early years of test-based accountability – when teachers and students are rapidly adjusting to new test formats – and then level off as "easy" ways to make gains are exhausted. However, a report from the Center on Education Policy (CEP) concludes that the plateau effect may be less prevalent in student testing than previously believed.

Drawing from CEP's database of reading and math test results from all 50 states going back as far as 1999, researchers looked for evidence of a plateau effect in 55 "trend lines" from 16 states with six to 10 years of consistent test data (for purposes of this study, a trend line referred to the movement in percentage of students reaching proficiency and above for one grade level and one subject in a single state).

While instances of plateaus were found in some state test scores, CEP reported that the problem is not pervasive across the nation. Of the trend lines studied, 15 exhibited a plateau effect, 21 showed steady increases in the percentage of students scoring at the proficient level and above, and 19 illustrated a zigzag pattern, meaning student performance increased and decreased multiple times.

The report also showed that, for a third of the trend lines studied, the greatest score gains were made in the 2003-04 period, during a time when testing under the No Child Left Behind (NCLB) law was fully established. It is suggested in the report that test results can increase substantially, even after a test has been in place for several years, if higher stakes are introduced in the accountability system.

This report is the second in a series of 2009 CEP reports that seek to analyze student achievement trends.

The Center on Education Policy, 2009

The Latest Research

Report: *One-Year Follow-Up Outcomes of Spanish and English Interventions for English Language Learners at Risk for Reading Problems. American Educational Research Journal, Vol. 46, No. 3, 744-781. (September 2009)*

What? This report provides one-year follow-up data on 215 English language learners (ELLs) with reading difficulties who received a supplemental first grade reading intervention in the language of their core reading instruction. Two experimental intervention studies were analyzed in the report. One study investigated the effectiveness of a Spanish reading intervention with students who were being instructed in Spanish in their classrooms. The other study investigated the effectiveness of an English reading intervention with students who were nonnative English speakers and were being instructed in English in their classrooms. Both of the studies were conducted with first graders and used randomized controlled designs.

The studies' treatment students received intervention for one school year in small groups for 50 minutes each day, as a supplement to their core reading program. Comparison students received what the schools typically provided to ELLs.

Findings from the studies revealed significant differences favoring the treatment students on Spanish and English measures, including decoding, spelling, fluency, and comprehension. The report concluded that ELLs at risk for reading problems who were provided a very intensive first grade intervention made and sustained gains through second grade, regardless of whether the intervention was in Spanish or English, in nearly all areas assessed.

Authors: Cirino, P., Vaughn, S., Linan-Thompson, S., Cardenas-Hagan, E., Fletcher, J., Francis, D.

Where? This report can be found on the SAGE publications website at http://aer.sagepub.com/cgi/content/abstract/46/3/744

Report: *Impacts of Comprehensive Teacher Induction: Results from the Second Year of a Randomized Controlled Study. (NCEE 2009 – 4072). Washington, DC: National Center for Educational Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education. (August 2009)*

What? A common policy response to the problems of turnover and inadequate preparation among beginning teachers is to support new educators with a formal, comprehensive induction program. However, currently there is little evidence to prove that investing in more comprehensive induction programs will help districts attract, develop, and retain beginning teachers. In an effort to evaluate the effectiveness of comprehensive teacher induction, this randomized controlled study compared outcomes of teachers offered intensive induction activities with full-time mentors to those of teachers with less intensive, less structured induction activities. The report includes information from 10 districts in which teachers were offered one year of comprehensive induction services ("one-year" districts) and seven districts in which teachers were offered two years of comprehensive induction services ("two-year" districts).

The study found that, in two-year districts, treatment teachers reported receiving more support than did their counterparts during their second year in the classroom. For one-year districts, treatment teachers received less support than their counterparts during their second year in the classroom. According to the report, in both one-year and two-year districts, there was no impact on teacher retention rates or overall student achievement.

Authors: Isenberg, E., Glazerman, S., Bleeker, M., Johnson, A., Lugo-Gil, J., Grider, M., Dolfin, S., Britton, E.

Where: This report can be found on the Institute of Education Sciences website at http://ies.ed.gov/ncee/pubs

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Report: *Improving students' reading comprehension skills: Effects of strategy instruction and reciprocal teaching. Learning and Instruction, 19(3), 272-286. (June 2009)*

What? The aim of this study was to investigate the effects of three different forms of strategy instruction – traditional reciprocal teaching, reciprocal teaching in pairs, and instructor-guided reading – on 210 elementary-school students' reading comprehension.

Students in the study were randomly assigned to either an intervention condition or a control condition. In the intervention condition, students were taught four reading strategies -- summarizing, questioning, clarifying, and predicting – and practiced these strategies in small groups (reciprocal teaching), pairs, or instructor-guided small groups. In the control condition, students were taught reading comprehension through traditional instruction, which included an extensive amount of text interaction.

The study found that, at both the post- and follow-up test, the intervention students attained higher scores on an experimenter-developed task of reading comprehension and strategy use than the control students who received traditional instruction. The study also showed that students who practiced reciprocal teaching in small groups outperformed students in instructor-guided and traditional instruction groups on a standardized reading comprehension test.

Authors: Sporer, N., Brunstein, J.C., Kieschke, U.

Where? This report can be found at http://dx.doi.org/10.1016/j.learninstruc.2008.05.003

The Latest Research

Report: *Understanding Reading First: What We Know, What We Don't, and What's Next. MDRC Policy Brief. (June 2009)*

What? This policy brief describes Reading First, the federally funded early reading program under the No Child Left Behind Act. The brief sets the context in which Reading First was implemented, reviews studies of the program, summarizes the findings, and discusses the program's implications for federal and state policy and for future research in the teaching of early reading.

To summarize the brief, Reading First did increase the provision of professional development for teachers, as well as reading coaches and supports for struggling readers, in schools that received funding. According to the brief, the program also influenced how teachers taught – in ways that are aligned with scientifically-based reading research (as summarized by the National Reading Panel in 2000) – which was a key goal of the legislation.

Unfortunately, the research shows that these improvements did not produce higher reading comprehension scores on average among students in Reading First schools. However, there is some suggestive evidence that Reading First funding may have improved comprehension in schools in which the effects on teacher instruction were larger.

Authors: Herlihy, C., Kemple, J., Bloom, H., Zhu, P., Berlin, G.

Where? This report can be found on the MDRC website at http://www.mdrc.org/publications/518/policybrief.pdf

Report: *Assisting Students Struggling with Mathematics: Response to Intervention (RTI) for Elementary and Middle Schools. (NCEE 2009 – 4060). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences, U.S. Department of Education. (April 2009)*

What? According to the Institute of Education Sciences, students struggling with mathematics may benefit from early interventions aimed at improving their mathematics ability, ultimately preventing subsequent failure. This practice guide provides eight specific recommendations intended to help teachers, principals, and school administrators use Response to Intervention to identify students in need of mathematics assistance. The goal of the guide is to address the needs of these students through focused interventions.

To develop the guide, the authors reviewed evaluations of mathematics programs for low-performing students and students with learning disabilities. In some cases, recommendations reflect evidence-based practices that have been demonstrated as effective through rigorous evidence. When evidence was not available, the recommendations reflect best practices as determined by the authors.

Authors: Gersten, R., Beckmann, S., Clarke, B., Foegen, A., Marsh, L., Star, J.R., Witzel, B.

Where? This report can be found on the Institute of Education Sciences website at http://ies.ed.gov/ncee/wwc/pdf/practiceguides/rti_math_pg_042109.pdf

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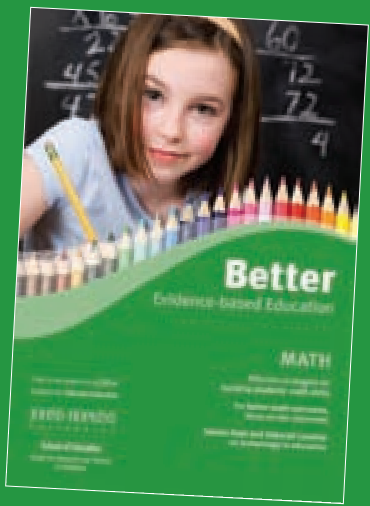

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