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A Comparison of Spiral Versus Strand Curriculum

Abstract: National and international assessments indicate that U.S. students lose ground in mathematics as they progress into middle and high school. It is suggested that the organization of traditional mathematics textbooks, which form the backbone of mathematics instruction, hinders acquisition of the foundational skills necessary for success in higher mathematics, thereby leading to low math performance. Traditional mathematics textbooks are organized into a spiral design where many topics are covered, but none are covered in depth. An alternative to the spiral organization, which is unique to Direct Instruction programs, is the strand design. Textbooks organized around a strand design focus on a relatively small number of topics over a long period of time. As topics are mastered, they are integrated into new strands that represent increasingly complex mathematical concepts. This article examines the disadvantages of the spiral design and shows how organizing textbooks into strands can increase the effectiveness of mathematics curricula.

Mathematics curricula are typically organized into a spiral design where numerous topics are revisited every year. Despite its prevalence, some educators are critical of the spiral design and, as far back as 1989, the National Council of Teachers of Mathematics noted the need to change the "repetition of topics, approach, and level of presentation in grade after grade" (p. 66). An alternative to the spiral curriculum is the strand curriculum where topics are treated in depth over a long period of time. Design of instruction can have a powerful effect on student achievement (Carnine, 1990), and the dismal state of achievement in mathematics among youth in this country warrants scrutiny of the spiral versus strand curricula.

National and international comparisons repeatedly indicate that U.S. children lack fundamental mathematical skills. The National Assessment of Educational Progress (NAEP) was administered to 4th, 8th, and 12th graders in the United States in 1996 and 2000 (U.S. Department of Education, 2001a). Results of the NAEP indicated that scores have steadily increased over the past 20 years. However, the gains for 4th graders were much higher than the gains for 8th- or 12th-grade students. There appears to be a *slump* in math achievement that begins shortly after fourth grade and continues into high school. The Third International Mathematics and Science Study (TIMSS) confirmed this phenomenon. The TIMSS was administered in 1995 to more than 500,000 students in 41 countries at three age levels (Masini & Taylor, 2000) and again to eighth graders in 1999 (U.S. Department of Education, 2001b). No other country had a sharper drop in math ranking than U.S. children (Loveless & DiPerna, 2000). It appears that U.S. students do not start out behind but fall behind during the middle-school years. As the British weekly, *The Economist,* put it: "The longer children stay in American schools, the worse they seem to get" (America's Education Choice, 2000, p. 17).

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Diverse learners fare the worst. Socioeconomic status accounted for 40% of the variance in scores of children in the United States, but it accounted for only 20% of the variance across all the participating TIMSS countries (Schmidt, Houang, & Cogan, 2002). This disparity is illustrated by the fact that 36 of the 41 participating countries outperformed the District of Columbia in mathematics, but only 6 countries scored higher than eighth-grade students in Iowa and Nebraska (Berliner, 2001.) Similarly, socioeconomic status accounted for about 60% of the difference in NAEP scores (Masini & Taylor, 2000). It appears that children who are advantaged do well, while others do not. Similar results occur in school districts around the country. Despite the efforts of local administrators, students of color and students from low-income homes have made few gains on basic skills exams in mathematics (Totso & Welsh, 2003).

Poorly designed curricula are seldom considered factors in creating educational inequalities. However, an analysis of mathematical concepts considered essential in Grades 1–8 revealed interesting differences between top achieving countries and the United States (Schmidt et al., 2001). Schmidt et al. (2002) found that top achieving countries covered a limited number of topics at each grade level and covered them for about 3 years. Foundation topics, such as whole number concepts, were introduced in the early grades, and more sophisticated mathematical topics were gradually covered in the later grades. No such logical progression was apparent in the United States. Prerequisite knowledge was not necessarily introduced first. Many more topics were considered essential at each grade level. In fact, the average duration of each topic was 6 years, suggesting that in the United States topics are covered superficially over a longer period of time. The result is that our textbooks are a "mile wide [and] an inch deep" (Schmidt et al., 2002, p. 13).

The design of textbooks is important because they form the backbone of education. Although good teachers provide instructional opportunities that go beyond textbooks, 75% to 90% of classroom instruction is organized around textbooks (Tyson & Woodward, 1989; Woodward & Elliott, 1990). As Farr, Tulley, and Powell (1987) noted, "Textbooks dominate instruction in elementary and secondary schools" (p. 59). Most textbooks have a similar appearance. This similarity occurs because 22 states, including most notably California and Texas, have statewide adoption procedures that require centralized textbook adoption. Approval by an adoption state is very lucrative for publishers; consequently they tailor their textbooks to meet the requirements of the big adoption states. The result is that textbooks published by different companies look much the same. This similarity would not be a problem if math textbooks were uniformly good, but unfortunately the design of traditional textbooks is flawed (Carnine, 1990; Carnine, Jitendra, & Silbert, 1997).

Textbooks may be poorly designed in a number of ways, and there is little agreement on what constitutes an ideal mathematics curriculum. Some mathematicians are critical of reform efforts known as constructivism (Open letter to United States Secretary of Education, Richard Riley, 1999), especially the de-emphasis on arithmetic algorithms. Some math educators claim that current reform efforts are insufficient (Battista, 1999). This article examines one aspect of curriculum design that is seldom mentioned in the debate—the difference between the spiral curriculum that is common to both traditional and constructivist mathematics textbooks and the strand curriculum that is unique to Direct Instruction programs. Four disadvantages of the spiral design will be discussed. Examples from *Connecting Math Concepts* (*CMC*; Engelmann, Carnine, Kelly, & Engelmann, 1996), a Direct Instruction mathematics program, will be used to explain how the strand curriculum eliminates the disadvantages of traditional basal textbooks organized in a spiral.

Spiral Curriculum

Textbooks organized around a spiral design are organized into 10–20 chapters or units that spiral for several years. Many topics are covered every year including place value, money, time, measurement, graphing, addition, subtraction, multiplication, division, fractions, decimals, geometry, patterns, probability, and statistics. Ratios, proportions, percents, number theory, integers, and the coordinate plane are added in the sixth-grade and middle-school textbooks. Concepts appear and are taught, then they disappear only to return the following year.

Scott Foresman-Addison Wesley Math (*SF-AW*; Charles, Barnett, et al., 1999) is representative of traditional basal mathematics textbooks. Jitendra, Salmento, and Haydt (1999) reviewed seven mathematics basal programs for adherence to nine instructional design criteria when teaching borrowing in subtraction across zeroes. The criteria included clear objectives, the absence of extraneous concepts or skills, adequate preteaching of prerequisite skills, explicitness, good use of instructional time, appropriate teaching examples, adequate practice, sufficient review, and effective feedback. *SF-AW* received 88.9% of the total possible points for adherence to the authors' design of instruction criteria. No text received a higher score, although one basal received the same score, suggesting that *SF-AW* is better than some and no worse than any of the popular mathematics basals, all of which are organized in a spiral design.

Examination of the scope and sequence in first through sixth grade reveals some of the problems with the spiral design. Two math concepts were selected, addition/subtraction and fractions, to illustrate the difference between the spiral and strand curriculum. Figure 1 shows the scope and sequence for these two important math concepts across the elementary-grade levels in *SF-AW* and *CMC*, which is organized in a strand design. *SF-AW* introduces addition/subtraction concepts in first grade in chapters 3, 4, 6, 12, and 13. Thereafter, addition/subtraction concepts are revisited every fall, except in second grade when they are covered in both fall and spring. Addition/subtraction of whole numbers makes its last appearance in fifth grade.

Fractions tend to spiral later in the year and with less frequency. Fractions first appear in second grade in chapter 12. Then they appear in third grade in chapter 10; fourth grade in chapters 9 and 10; fifth grade in chapters 7, 8, and 9; and sixth grade in chapters 6 and 7. Two chapters are devoted to fractions in each of two middle-school textbooks as well.

Although the intent is to treat each concept with increasing depth at successive grade levels, the functional result is that students acquire a superficial understanding of math concepts. The spiral design hinders student learning by (a) treating topics superficially, (b) introducing concepts at an inappropriate rate, (c) minimizing academic learning time, and (d) providing insufficient cumulative review. These four limitations to the spiral design will be described below followed by a discussion of how the strand curriculum addresses each of those disadvantages.

Topics

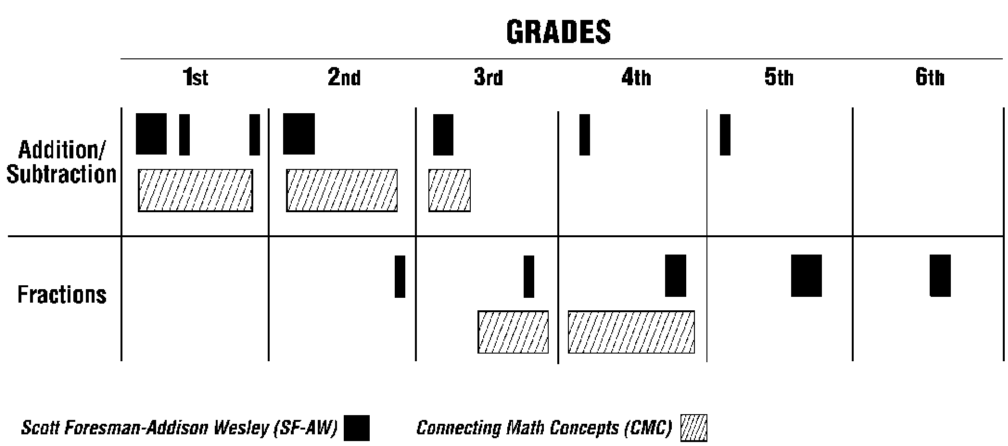
In a spiral curriculum, many topics are covered but only briefly. On the average, teachers devote less than 30 min of instructional time across an entire year to 70% of the topics they cover (Porter, 1989). The result of teaching for exposure is that many students fail to master important math concepts.

For example, *SF-AW* teaches fractions in chapter 10 of the third-grade text. Students spend 1 week exploring the concept of equal parts of fractions and learning to write, order, and compare fractions. Then they spend 1 week exploring fractions as sets, mixed numbers, and addition and subtraction of fractions and 1 week on customary linear measurement. After the 3-week unit is completed, students are exposed to the following math concepts before they ever see fractions again in fourth grade: decimals, metric linear measurement capacity, weight, temperature, probability, reading and making graphs, math facts, place value, time, addition, subtraction, money, multiplication, division, solids, triangles, polygons, quadrilaterals, perimeter, area, and volume. This laundry list of topics covered in third and fourth grade leaves little doubt that children are exposed to so many topics that there is little chance that they will master any of them. With no review and so much intervening information, it is not surprising that fourth-grade students remember little about fractions from third grade and require the reteaching that is built into spiral curricula.

To illustrate further, the concept of "fractions equal to 1" is essential not only for finding common denominators and simplifying fractions but also for solving ratios and proportions (Carnine et al., 1997). *SF-AW* first introduces "fractions equal to 1" in third grade in one lesson. Story problems are used to promote the understanding that "you can use fractions to name equal parts of a whole" (Charles, Barnett, et al., 1999, p. 414). A year later, "fractions equal to 1" are covered in one item in the lesson on mixed numbers when a problem asks, "How many 1/4 strips in 1?" (p. 392). Students spend 2 days on equivalent fractions in fourth grade. In fifth grade they are expected to use "fractions equal to 1" to find equivalent fractions, and in sixth grade they finally use "fractions equal to 1" to solve addition/subtraction of fractions with unlike denominators. This brief, yearly exposure to the concept of "fractions equal to 1" makes it highly unlikely that students will remember these difficult, yet essential, concepts from year to year.

Figure 1

Scope and sequence of instruction in addition/subtraction and fractions in the Scott Foresman-Addison Wesley *spiral curriculum versus* Connecting Math Concepts *strand curriculum.*



The fact that fractions are taught at the end of the text in second, third, and fourth grade further reduces students' opportunity to learn fraction concepts. If the teacher falls behind, or if end-of-the-year activities reduce the amount of time allocated for math instruction, the topic may not be covered at all. Not surprisingly, both Course A and Course B of *Middle School Math* (Charles, Dossey, Leinwand, Seeley, & Vonder Embse, 1999) include two chapters devoted to fractions, suggesting that publishers anticipate that middle-school students will not have mastered basic fraction concepts and operations.

For the lucky students who learn fractions the first time, the repetition represents wasted instructional time. For the students who did not learn it the first time, the problem is more insidious. There is never any bottom line for mastery so teachers are unconcerned when students don't "get it" in second grade because they will "get it" again in third, fourth, or even fifth grade. Students learn that if they don't understand something, they just need to "lie low" for a few days until the topic goes away.

Rate

Another problem with the spiral design is that the rate for introducing new concepts is often either too fast or too slow. All concepts are allotted the same amount of time whether they are easy or difficult to master. Units are approximately the same length, and each topic within a unit is 1 day's lesson. For example, the fourth-grade text of *SF-AW* allocates exactly the same amount of time to addition/subtraction of fractions with like denominators and addition/subtraction with different denominators—1 day for addition and 1 day for subtraction. Assuming the math period is the same length of time, some days there will be too much time (leading to wasted instructional time), and some days there will not be enough time to introduce, let alone master, the concept. The fact that an entire class period must be devoted to a single concept makes it difficult to sequence instruction to ensure that students acquire necessary preskills before introducing a difficult skill like addition/subtraction of fractions with unlike denominators.

Academic Learning Time

Academic learning time has been defined as the amount of instructional time during which students are on-task and experiencing success. Research suggests that academic learning time is positively associated with academic achievement (Fisher et al., 1980; Good & Grouws, 1979; Rosenshine, 1980; Stallings, 1980). There are wide variations in the amount of time that is allocated for mathematics (Porter, 1989), and even greater variations in students' opportunities to learn during allocated time (Carnine, Jones, & Dixon, 1994).

When the rate for introducing new content is inappropriate, academic learning time may decrease because students are either (a) unsuccessful with new and difficult content, or (b) bored by the slow pace and redundancy. Often, an entire math period (30–40 min) is too long to spend on a single concept. Either the teacher presentation will be too long or the amount of independent work will be tiresome. Students may lose interest, resulting in high rates of off-task behavior and less academic learning time.

Many mathematics programs avoid this problem by including a variety of "fun" activities that may or may not be related to the math topic of the day. The obvious problem with this approach is that it decreases the amount of functional instructional time, which also reduces academic learning time. Whether instructional time is lost because students become bored by copious amounts of seatwork or because the amount of time actually allocated to mathematics instruction is decreased by frivolous activities, the result is less academic learning time, which has a negative effect on academic achievement.

Review

Another disadvantage of the spiral design is that it does not promote sufficient review once units are completed. There may be some review of previously introduced topics within the chapter, but once students move on to the next chapter previous concepts may not be seen again until they are covered the following year. Distributed review facilitates mastery more effectively than massed practice (Dempster, 1991) because new concepts are reinforced over time. Carnine, Dixon, and Kameenui (1994) identified four components of effective review. It must be sufficient to promote fluency, distributed over time, cumulative with new information integrated into more complex skills, and varied enough to facilitate generalization.

The teacher's manual for the third-grade level of *SF-AW* provides one optional "skills practice" worksheet that includes fractions problems. There is also one activity in the last lesson in the text where students must write probabilities as fractions. There are several problems with this amount and type of review. First, one optional worksheet is not sufficient to assure students can perform tasks with fractions as introduced in the previous chapters, and it is certainly not distributed over time. The activity with probability could provide integrated and varied practice that would help students learn the relationship between fractions as ratios and fractions as part of an area or set (which is how fractions were introduced previously), assuming that they possessed all the necessary preskills and were systematically guided toward that learning. As presented, it serves little purpose. This author was unable to find a single review of fractions in the fourth-grade text prior to the chapter on fractions. Students do make a pinwheel by dividing a square into four equal parts in chapter 4, but fractions are not explicitly mentioned.

In all fairness, there is slightly more review of addition/subtraction concepts than there is of fraction concepts. The text includes cumulative review, mixed review, and test preparation in addition to the review and practice pages at the end of each section. Previously learned problem types are seldom systematically incorporated into new, more complex mathematical concepts. It would be very difficult to provide integrated review when so many unrelated and discrete topics need to be covered. The most common form of review in a spiral curriculum consists of isolated problems on homework assignments.

The spiral curriculum is flawed because it limits student opportunities to master critical mathematical concepts. Exposure to many concepts rather than emphasis on a few key concepts may lead to a superficial understanding of mathematical skills that are critical for learning high level math concepts. The spiral design also makes it difficult to control the rate at which concepts are introduced and to structure allocated time to maximize academic learning time. Finally, the spiral design does not lend itself to review that is calculated to provide both mastery and generalization of previously learned mathematical skills.

Strand Curriculum

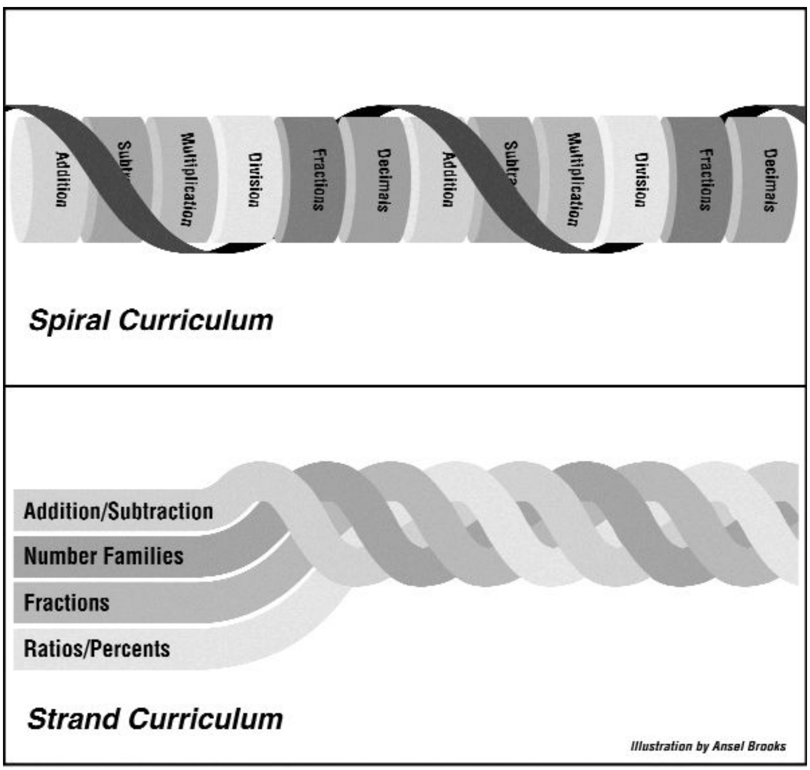
The alternative to a spiral design is the integrated, strand curriculum. An integrated strand curriculum avoids the shortcomings of a spiral curriculum. Each lesson is organized around multiple skills or topics rather than around a single skill or topic. Each skill/topic is addressed for only 5 to 10 min in any given day's lesson but is revisited day after day for many lessons. Organizing lessons so that skills/topics are revisited for a few minutes a day over many days is referred to as a strand organization. Figure 2 provides a graphic illustration of the spiral versus the strand curriculum (Snider & Crawford, 2004). Skill strands are woven together over time to create increasingly complex mathematical understandings.

CMC is the only basal mathematics curriculum that is organized around a strand curriculum. It is easy to see the difference between *CMC* and *SF-AW* by examining the scope and sequence for instruction in addition/subtraction and fractions as shown in Figure 1. Addition/subtraction is introduced in Lesson 11 of Level A (first grade) of *CMC* and continues until the last lesson in that level. Addition/subtraction of number families and fact memorization begin at Lesson 10 of Level B (second grade) and continue throughout the year. Column addition is taught from Lesson 32–82 and column subtraction from 65–115. Level C (third grade) includes some review and introduces more complex column addition/subtraction in the first 40 lessons or so. Instruction after that consists of using addition/subtraction to solve increasingly complex word problems.

Fractions are not introduced until Level C (third grade), Lesson 53 and then they appear in almost every lesson until all fraction concepts are mastered. Fractions appear in Lesson 1 of Level D (fourth grade) and in almost every lesson thereafter. It is important to reiterate that in every lesson, several ongoing topics are covered. For example, Lesson 53 of

Figure 2

Illustration of spiral versus strand curriculum adapted from Snider and Crawford (2004).



Note. From Nancy Marchand-Martella, Timothy Slocum, Ronald Martella, *Introduction to Direct Instruction.* Published by Allyn and Bacon, Boston, MA. Copyright (c) 2004 by Pearson Education. Reprinted by permission of the publisher.

Level C, where fractions are first introduced, also includes exercises related to place value, problem solving, number families, multiplication, the coordinate system, and math facts. Instruction based on strands avoids all the problems of the spiral curriculum by (a) treating a limited number of topics in depth, (b) varying the rate at which concepts are introduced, (c) maximizing academic learning time, and (d) providing cumulative and integrated review of previously learned concepts.

Topics

CMC focuses on a relatively small number of big ideas. Big ideas include concepts such as number families, operations with whole numbers, "fractions equal to 1," and using tables to solve a variety of word problems. Emphasis on a limited number of big ideas promotes mastery rather than merely teaching for exposure. Organizing lessons into strands makes it possible for topics to be treated in depth. The strand design allows important concepts to be reinforced over days, weeks, and even years. Once an important concept is introduced, it appears in every lesson until it is mastered, at which point that skill is integrated into a more sophisticated mathematical concept. Rather than ignoring difficult math concepts in the hope that they will "go away," children learn that success on today's lesson ensures success in the future.

The concept of "fractions equal to 1" provides a good example of how the strand curriculum promotes mastery. Connecting the procedure for finding equivalent fractions to the concept of "fractions equal to 1" is typically one of the most difficult topics to teach. For example, beginning in Level C of *CMC*, students are taught that fractions consist of the bottom number that tells how many parts are in a whole, and a top number that tells how many parts are used. From the earliest examples, students learn the concept that fractions can be greater than 1, less than 1, or equal to 1. Students are taught how to apply the concept by writing fractions equal to 1 (e.g., 4/4 or 7/7). Then students are taught that numbers multiplied by 1 yield an equivalent value, which provides an explicit strategy for finding equivalent fractions. Students understand the new concept because "fractions equal to 1" are very familiar. Students continue to apply the strategy of multiplying by a "fractions equal to 1" in increasingly complex ways. In Level E (fifth grade) when students add and subtract unlike fractions, they use "fractions equal to 1" to convert the two unlike fractions into equivalent fractions with common denominators. *CMC* continues to apply the idea of multiplying by a "fractions equal to 1" in other areas as well. In Level E students use this same strategy to solve ratio problems and ratio-table problems. Eventually, students use ratio tables that employ both mixed fractions and percentages to solve problems that stump many adults. The strand design promotes the depth of understanding that makes this level of sophistication possible.

Rate

Organizing lessons into strands alleviates a number of problems found in the spiral curriculum. Unlike a spiral curriculum where one topic is covered per lesson, a number of different topics are covered in each lesson of the strand curriculum. The rate at which concepts are introduced can be controlled by the number of minutes and the number of consecutive days that are spent on a concept. Less time each day and more days can be allocated to particularly difficult topics. Easing into complex strategies, both in terms of quantity and complexity, avoids overwhelming students with a barrage of new information (Carnine, 1997). Gradual introduction of complex strategies also provides scaffolding for naïve learners. The amount of teacher direction can be gradually decreased until learners can perform a task independently.

Preskills can be introduced and mastered before they are needed to perform more complex operations. The consistency of the rate and logic of the sequence for introducing fractions over 2 years is only possible because of the strand design in *CMC*. For example, before students are taught to find equivalent fractions by multiplying by a fraction "equal to 1" (e.g., $3/4 \times 2/2 = 6/8$), students learn necessary multiplication facts, they learn that 1 can be expressed as a fraction, and that multiplying by 1 doesn't change the value of a number. These concepts are introduced at a reasonable rate over time, promoting high levels of student success, thereby increasing academic learning time.

Academic Learning Time

In addition to structuring lessons for academic success, strands promote academic learning time because a variety of topics are covered each day. Planned variation promotes on-task behavior because students are not engaged in any one type of activity for too long (Colvin & Lazar, 1997). This variety is more interesting than spending 30–40 min on a single topic. Some of the topics are challenging because they are new and difficult, others are easier because they are review. This mix of topics and difficulty promotes academic engaged time. It is far more interesting to work 20 problems that include a variety of problem types than to work 20 problems that are all exactly the same.

Review

The mix of problem types also facilitates effective review, promoting mastery. Strands provide sufficient practice over time for students to become both accurate and rapid in their responses. Students work only a small number of each type of problem in each lesson, but the problems are presented over a long period of time. Once students can perform a skill without hesitation, that skill is integrated into other, more complex mathematical procedures. For example, in Level C, Lesson 53 where fractions are first introduced, students complete four workbook parts with guidance from the teacher on number families, fractions as whole numbers, multiplication facts, and complex addition facts. Students work eight different types of problems independently, and there are no more than four of any one type.

An added benefit to providing a variety of problem types on independent work is that it teaches persistence, an important test-taking skill. Low performing students often give up in frustration as soon as they encounter a difficult problem. Their lack of persistence can depress scores on district and statewide assessments. Teachers can use daily independent work to teach students to mark any difficult problems so they can come back to them, but to keep working.

The strand design promotes student mastery by focusing on a limited number of big ideas rather than teaching for exposure. The component skills for understanding these big ideas can be introduced at an appropriate rate to assure student success. Many topics are covered in each lesson in strand curricula, whereas spiral curricula teach one topic per lesson. Multiple topics eliminate the problem of not having time to teach difficult concepts adequately or having too much time in the math period for easy concepts. Curricula designed around strands promote academic engaged time not only because students experience success but also because an interesting mixture of activities occurs during any single math lesson. Mastery and success are also promoted through the use of practice that is distributed over time and systematically integrated into more complex skills.

Although this article has focused on the design of mathematics curricula, it is important to note that the strand design is not unique to Direct Instruction mathematics programs. The strand design is found in other Direct Instruction programs, such as *Expressive Writing 1* and *2* (Engelmann & Silbert, 1983, 1985) and *Reasoning and Writing* (Engelmann &

Silbert, 1991). Every lesson includes instruction in more than one aspect of written expression—handwriting fluency, grammar, mechanics, sentence/paragraph writing, and thinking skills. The advantages of designing curricula around strands are not limited to the content area of mathematics.

Conclusion

The strand curriculum intertwines topics over time, increasing students' understanding of mathematical concepts, much as fibers in a rope are woven together for strength. Given the advantages of a strand curriculum, it is not surprising that numerous research studies have documented the effectiveness of *CMC* (Adams & Engelmann, 1996; Crawford & Snider, 2000; Przychodzin, Marchand-Martella, Martella, & Azim, 2004; Tarver & Jung, 1995). What is surprising is that other textbook publishers have not followed suit.

Results of standardized mathematics assessments suggest that students in the United States are increasingly deficient in mathematics as they enter middle and high school. Masked by the averages lie troubling differences in performance between white, middle-class students and less affluent children of color. If accuracy and fluency in basic skills are necessary for acquisition of higher-level conceptual mathematical understanding (Wu, 1999), could it be that the gradual decline of U.S. students in mathematics as they progress through school is related to the inadequate foundation laid by traditional elementary mathematics basal textbooks?

The spiral design found in the majority of math textbooks does not promote mastery of the fundamental mathematical concepts on which higher-level mathematics are built. The potential for the strand curricula to improve textbooks cannot be underestimated. Osborn, Jones, and Stein (1985) suggested that "improving textbook programs used in American schools is an essential step toward improving American schooling" (p. 10). Although organizing textbooks around strands is not a panacea for eliminating poor performance in mathematics, it is a powerful tool for improving instruction. Textbooks are part of teachers' toolbox and educators need to improve their "access to tools that work" (Carnine, 1992, p. 1). The strand design is one component of an effective instructional program that increases opportunities for *all* children to learn.

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