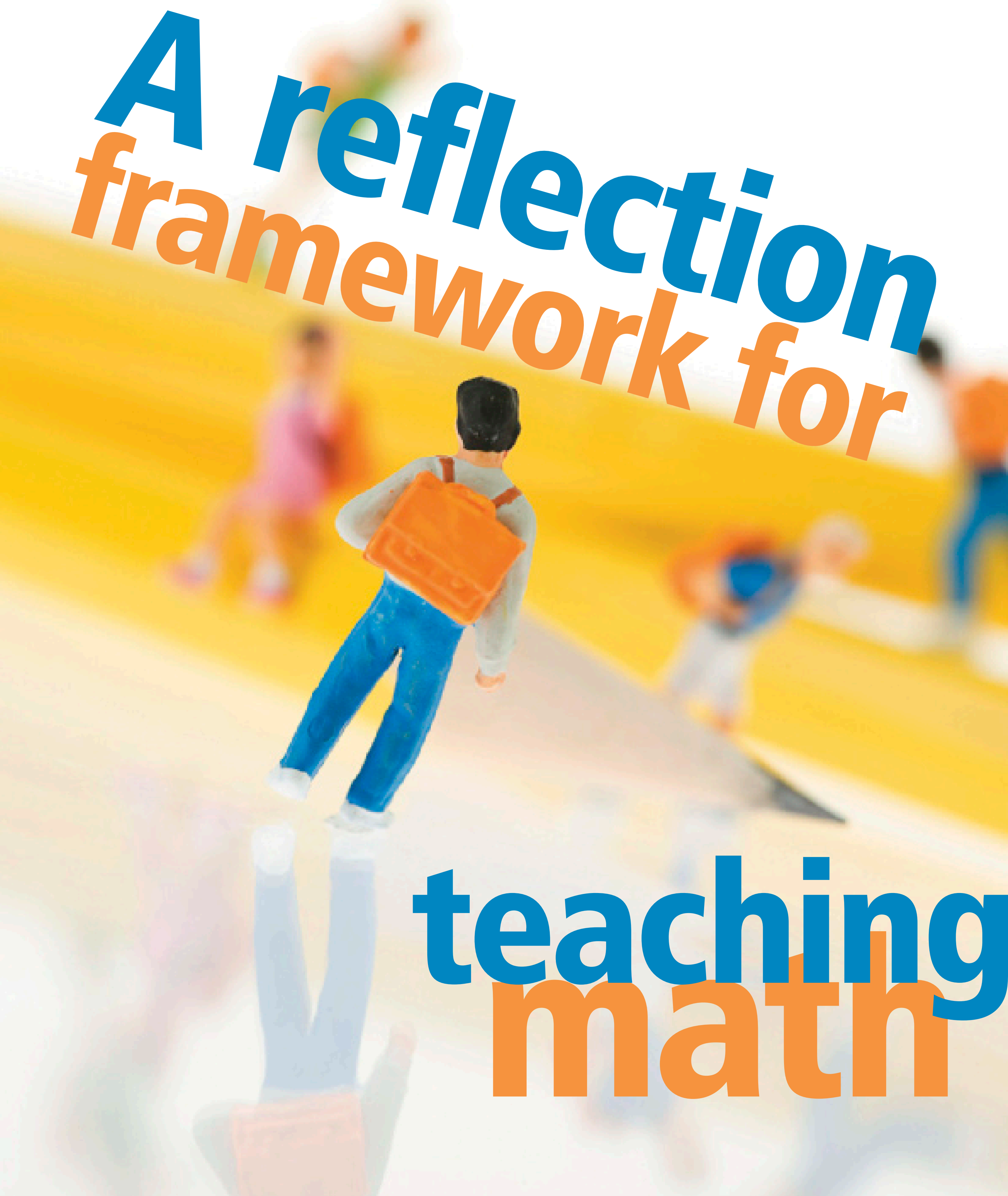
A reflection framework for teaching math



Evaluate the quality of your instruction by using the eight dimensions of M-Scan, an observation tool that links math standards with day-to-day practice.

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Mathematics teachers confront dozens of daily decisions about how to instruct students. It is well established that high-quality instruction provides benefits for students with diverse learning and family backgrounds (Rowan, Correnti, and Miller 2002; Sanders and Horn 1994). However, it is often difficult for teachers to identify the critical aspects of a successful mathematics lesson as they strive to improve their practice. To address this problem, our research team at the University of Virginia developed the Mathematics Scan (M-Scan), an observation tool to measure the quality of mathematics instruction.

To introduce educators (including teachers, mathematics specialists, instructional coaches, and administrators) to the M-Scan framework, we first describe the development of the M-Scan. Next, we outline the eight dimensions of classroom instruction in the M-Scan that comprise a high-quality mathematics lesson and describe a model lesson to make the framework and its dimensions concrete. Finally, we summarize the M-Scan dimensions in a table that can be used for reflection after a lesson, making suggestions for how to integrate dimensions of the M-Scan into daily practice.

Development

The M-Scan tool design is based on standards advanced by the National Council of Teachers of Mathematics (NCTM). Two publications supplied vision for mathematics teaching and learning: *Mathematics Teaching Today: Improving Practice, Improving Student Learning* (NCTM 2007) and *Principles and Standards for School Mathematics* (NCTM 2000). The five Process Standards (NCTM 2000) and the seven Content Standards for Teaching and Learning Mathematics (NCTM 2007) in these books are explicitly linked to dimensions of the measure. NCTM's Principles also provided the foundation for the M-Scan work. Specifically, the Equity Principle communicates the need for high expectations and strong support for all students (NCTM 2000). According to this Principle, all children can learn mathematics when they are given access to a high-quality instructional program that supports their learning. The articulation of clear, concise aspects of a quality mathematics lesson in ways that can be converted into actual classroom practice represents an important step toward achieving high-quality mathematics teaching and learning for all students.

Although *Principles and Standards* (NCTM 2000) is highly regarded, applying all the recommendations to daily work is hard for teachers to do. The M-Scan offers a list of important features to consider when planning and implementing a mathematics lesson or instructional unit. The M-Scan was adapted from a data collection tool, the Scoop notebook (Borko et al. 2005; Borko, Stecher, and Kuffner 2007; and Stecher et al. 2003). The research team used eight dimensions from the Scoop scoring guide to link the NCTM Standards to dimensions that can be observed in the classroom. Also, the Classroom Assessment Scoring System, a broader measure of classroom quality and teacher-child interaction, offered a structure for establishing an observational measure and served as a reference for the development of the M-Scan (Pianta, LaParo, and Hamre 2008). The M-Scan offers teachers a tool for self-reflection because it facilitates the translation of principles exemplified in NCTM's Standards to everyday mathematics classroom practice. Extensive video observations and conversations with teachers and mathematics educators confirmed its usefulness for this purpose (Walkowiak et al. unpublished manuscript).

Dimensions

Educators should keep in mind two guidelines while using this measure. First, although the tool offers eight dimensions to use for reflection, not every lesson will be "high" on all dimensions. In fact, watching hundreds of lessons has helped the researchers who developed the M-Scan realize that each teacher has different strengths reflected in the tool's dimensions. Second, each dimension is unique and should be considered separately. However, they overlap somewhat. Often a lesson that exhibits high quality in one dimension is strong in related dimensions as well. As you reflect on how a lesson fits with the dimensions described below, consider the list of questions in **table 1**.

Lesson structure

A well-designed math lesson must be logical and coherent, leading students to a deeper understanding of the mathematical concepts by the end of the lesson. Students should be given time to process new information, connect it to prior learning, and synthesize their thoughts at the end of class.

Feeling pressured by the long list of skills and content that students must learn to pass state tests, classroom teachers may pack many concepts or skills into a lesson, often resulting in a lack of conceptual coherence. A recent international study of math and science showed that typical lessons in the United States often lack logical order and coherence, specifically, U.S. lessons focused on several math topics within one lesson without connecting the different components to a single, central mathematical idea (Hiebert et al. 2005). When planning a lesson, teachers should keep the central mathematical idea in mind as they select and sequence activities and problems for students to complete during class.

Multiple representations

Teachers can use a variety of representations to help learners develop a deeper understanding of mathematical concepts and to think more flexibly about complex problems. When students represent problems in different ways, they become more capable of transferring the information they have learned to new situations. According to NCTM's Process Standard, students should "create and use representations to organize, record, and communicate mathematical ideas, and select, apply, and translate among mathematical representations to solve problems" (NCTM 2000, p. 206). For English language learners in particular, visual representations provide a way to access math that does not rely exclusively on written or spoken words (Coggins et al. 2007).

To strengthen a math lesson, teachers should introduce new concepts using several relevant representations and then allow their students to demonstrate their understanding of difficult problems with their choice of representations. Encouraging students to communicate their understanding of an idea with their own representations challenges them more than solving activity sheet problems where representations are provided for them. Students' use of representations to help them build understanding and communicate information to others promotes understanding (Greeno and Hall 1997). Also, encouraging students to consider the advantages and disadvantages of various representations for different tasks will further solidify concepts.

Mathematical tools

To fully develop understanding, students must be able to represent mathematical ideas using concrete materials. Tools in an elementary school classroom may include fraction strips, pattern blocks, cubes, base-ten blocks, protractors, rulers, or other materials. Although tools are one of many representations that a student may use, these hands-on materials help students make sense of abstract mathematical ideas and are important to include in a sequence of lessons developing a new concept. When elementary school students are in the early stages of understanding key mathematical ideas, their understanding can be enhanced by representing ideas with hands-on tools before they use pictures or symbols (Bruner 1966).

Furnishing students with tools to use is just a first step in a well-designed lesson. A next step might be to ask them to explore a problem with

TABLE 1

Teachers can use these questions as a framework to reflect on a lesson's eight dimensions, to think about what worked well, and to consider what needs to be changed in a future lesson.

M-Scan Dimensions	Framework Questions
Structure of the Lesson	• Which mathematical concept is most important for students to grasp today? • Are the activities mathematically related and coherent? • Has enough time been provided for students to make sense of the big mathematical ideas during the lesson? • Does the flow of the lesson facilitate students' deeper understanding of the mathematical concepts?
Multiple representations	• Are a variety of representations (graphs, pictures, symbols, charts, diagrams, or manipulatives) used during instruction? • Do students use these representations in meaningful ways as they explore the concepts? • Can students translate back and forth between different representations to demonstrate their understanding of the concept?
Use of mathematical tools	• Do students have the opportunity to use appropriate math tools (other than paper, textbooks, or chalkboards) to investigate concepts and solve problems in class? • Are connections made between the tools and the mathematical concepts?
Cognitive depth	• Do selected tasks connect to underlying concepts, or do the tasks mainly focus on memorization? • Are some of the tasks open-ended? • Are feedback, modeling, or examples included that promote complex thinking by students? • Are students encouraged to make conceptual connections during the lesson?
Mathematical discourse community	• Do students consistently participate throughout the math class and play a substantive role in directing the content of math discussions? • Do students often talk to each other and share mathematical thinking and language? • Are questions focused on mathematical thinking (processes, strategies, and solutions) rather than on correct answers? • Are students' ideas, questions, and input frequently solicited?
Explanation and justification	• Are students often required to provide explanations and justify their reasoning? • How often are "what, how, why" questions asked to solicit student explanations or justifications? • Do student explanations focus on conceptual understanding of the concept rather than procedural steps?
Problem solving	• Are students engaged in problems that allow them to grapple with mathematical concepts, or are they doing exercises for which they are practicing an already-learned procedure? • Does the lesson encourage multiple strategies to solve each problem? • Do students have a chance to create their own problems?
Connections and applications	• Are connections often made between the mathematics learned in the lesson, other math concepts, disciplines, life experiences, and the world? • Do students apply the math they learn to the world around them? • Is this lesson relevant to students' lives?

certain tools and then discuss ways to use the tools to solve the problem. Later, students need to solve problems on their own using tools to gain a deeper understanding of key mathematical ideas. Not every lesson needs to incorporate tools, because a variety of other representations and approaches exist to help students learn. However, appropriate, timely use of tools can promote and enhance students' understanding of mathematical ideas.

Cognitive depth

Cognitive depth examines the type and level of thinking expected of students in order to successfully solve selected problems or tasks. Achieving cognitive depth requires design and implementation of a lesson that builds toward understanding of key concepts while engaging students with appropriately challenging tasks. A *mathematical task* is a classroom activity that focuses students' thinking on a specific mathematical idea (Stein, Grover, and Henningsen 1996). The choice of worthwhile tasks is important because students spend much of their class time working on problems or tasks (National Center for Educational Statistics 2003). Worthwhile tasks engage students' intellect; develop mathematical understandings and skills; and require problem formulation, problem solving, and mathematical reasoning (NCTM 2007). However, too often lessons focus on many small procedural problems at the expense of open-ended problems requiring multiple, related steps (Firestone, Mayrowetz, and Fairman 1998).

The implementation of worthwhile tasks is also crucial to maintaining cognitive depth throughout a lesson. Sometimes, when students begin to struggle with a difficult task, a teacher transforms the task into a series of simpler exercises or procedures. When this occurs, students do not achieve the depth of understanding necessary to promote learning. When designing a unit, think about how to engage students in tasks and conversations that will help them understand important mathematical ideas with cognitive depth.

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Mathematical discourse community

Teachers play a critical role in developing the discourse community of a classroom. Teachers design questions and tasks that engage students and challenge their thinking, decide when to give clarifications or when to let students grapple on their own, and facilitate rich conversations focused on mathematical thinking (NCTM 2007). This dimension considers conversations that occur between teachers and students and among students. In elementary school classrooms, high-quality settings enable students to use communication to organize and consolidate their mathematical thinking, share their ideas clearly with members of the classroom community, analyze and assess strategies shared by others, and use mathematical language to express ideas (NCTM 2000).

Some teachers believe that explaining the important ideas themselves is more efficient because it takes less time for students to get pertinent information. However, the messy process of discussing and questioning facilitates greater learning for students. When students are comfortable asking questions, challenging one another, and seeking answers themselves, they become more engaged. Active engagement in classroom discourse is a key part of learning.

Explanation and justification

Reasoning and proof are considered fundamental aspects of mathematics (NCTM 2000).

Mathematical reasoning develops among students in classrooms where teachers require them to explain their thinking and justify their problem-solving approaches. Teacher questions and student responses are both crucial elements of this dimension. Instructors must ask probing questions that hold students accountable for articulating their reasoning and for trying to understand ideas shared by others. Here are a few examples of questions that encourage explanation and justification:

- **Why** do you think it is true?
- **Does** anyone think the answer is different, and why do you think so? (NCTM 2000, pp. 56–58)
- **Why** does that work?
- **Does** this solution strategy always work? Why, or why not?

Students further develop their reasoning skills when they articulate their thinking to their classmates, as partners or in small groups, or when they write explanations for their answers. When students share their solution strategies, teachers and other students are often able to recognize and address misconceptions.

Problem solving

Many people consider problem solving to be the most essential element of a math lesson. The usefulness of mathematical ideas and skills are limited without the ability to solve problems (NCTM 2000). Ideal problem-solving instruction engages students in problems that require grappling with important mathematical concepts and offers students opportunities to generate and use multiple strategies to find solutions to interesting, challenging problems. An emphasis on only one strategy, particularly a set of procedures, poses challenges for struggling learners, who often have difficulty remembering teacher-given steps for solving a problem (Allsopp, Kyger, and Lovin 2007).

Researchers who have analyzed videos of many classrooms in the Trends in Mathematics and Science Study (TIMSS) found that students spent 66 percent of their time in class practicing familiar procedures rather than engaging in problem solving. In many lessons, teachers demonstrated familiar procedures, and students repeated the procedure in a series of exercises (Hiebert et al. 2005). In an ideal lesson, students are allowed time to share their thinking as they try to solve the problems in class. An incorrect answer can provide as much opportunity for learning as a correct one. Discussing the reasoning and strategy behind the incorrect answer can clarify understanding and address misconceptions among students. During a lesson that is strong in the problem-solving dimension, students engage throughout the lesson in meaningful, challenging problems rather than work on exercises that require practicing an already-learned procedure.

Connections and applications

Mathematics is not a collection of separate topics and activities; it is an integrated discipline. Connections and applications provide anchors for mathematics teaching and learning. Students must understand how mathematical ideas interconnect and build on one another toward a coherent whole, as described by the NCTM Process Standards (NCTM 2000). Students ought to also connect and apply mathematics to other subjects and to their daily lives. Developing mathematical tasks that build on students' experiences provides relevance for students. Their ability to articulate their mathematical understanding in the context of prior knowledge and experience gives their teachers insight into students' conceptual understanding as well as their lives outside the classroom (Lemons-Smith 2009).

Researchers who study how learning occurs emphasize the importance of making connections. Students are more likely to remember new concepts when they relate those concepts to other information they know (Willingham 2000), explore underlying concepts, and look for connections to previously learned information. For example, students understand decimals more easily when they connect them to fractions.

In addition to connecting concepts, connecting strategies is important. When faced with two similar problems, many students must be reminded to connect them. Only then can they apply previously learned strategies to the new problem (NRC 2003). Throughout each lesson, encourage your students to recognize and use connections among mathematical ideas as they work to understand new concepts.

Improving teaching and learning

To improve the quality of instruction, NCTM suggests that teachers frequently analyze what they and their students are doing (NCTM 2007). Lesson planning is an iterative process. First, teachers plan a lesson and implement it with their students. Next, they reflect on how it went and consider how to make adjustments for the next group of students or the next lesson in the sequence. Finally, they prepare and conduct the next lesson. The M-Scan offers teachers a framework for reflection and analysis so that they can think concretely about aspects of their lesson and implement the next lesson with instructional quality in mind.

In today's elementary school classrooms, planning time is limited, and teachers are pulled in many different directions. It is often difficult for teachers to find time to implement new ideas that they have learned about or read. We hope that teachers will use **table 1** as a springboard for discussions at a team or faculty meeting. Teachers can reflect on all eight dimensions and think about which dimensions represent their strengths or areas they would like to improve. We suggest setting up peer observations with colleagues or videotaping lessons in order to reflect on how these dimensions are demonstrated in specific lessons.

A model lesson for reflection

We observed a class with a high percentage of English language learners in a suburban school. Transcripts from a third-grade lesson about patterns is provided (see the **appendix** on pp. 247–48). We chose to use a lesson transcript rather than a summary because the former furnishes teachers' and students' authentic voices.

Daily instruction in elementary school classrooms is an artful balancing act, and most lessons will not be "perfect" on all dimensions. Considering the context for each individual lesson is important when reflecting on its quality; some dimensions may be highlighted more in certain types of lessons than in others. This lesson met high standards on most dimensions of the M-Scan:

- **Lesson structure** rated high because the lesson was well organized and all components were connected to the concept of patterns.
- **Pacing** by the teacher ensured coherence, leading students to a deeper understanding of the concept of patterns.
- **Class discussion** at the end of the lesson (i.e., students sharing verbally) helped them make sense of what they had learned. The teacher then assigned relevant homework to extend their thinking.
- **Multiple representations** was a strong dimension for this teacher. She often used more than one representation; she showed students a variety of patterns, including patterns in shapes, letters, colors, and numbers. Students used several representations when they were developing the concept of patterns, and they were able to choose their own basket of materials (letters, blocks, fruit) to create a pattern. They were also required to explain their representations to the group. At the end of the lesson, students drew a picture and wrote their own definition of *pattern* to demonstrate their understanding.
- **Math tool use** was a strong component of this lesson. As students created their own patterns with a partner, the tools gave them vital opportunities to solidify the concept of patterns. The teacher helped students make connections between the tools and concepts when she had them explain and extend their patterns. She circulated throughout the room while students made their patterns, reminding them of the definition of patterns and encouraging them to check to see if their patterns were repeating.
- **Cognitive depth** in this lesson was also strong. Creating their own patterns was a worthwhile task. One student pair created a growing pattern, which sparked an interesting discussion. The teacher provided some examples that promoted complex thinking, including a set of stars that was not actually a pattern.
- **Discourse** in the math community was high quality, as you can see by reading the classroom conversations (see the **appendix**). Students participated often in the class discussion, sharing their mathematical language and thinking. The teacher asked

questions, for example, "Is this a pattern? Our definition says a pattern is a set of shapes that repeats over and over again. Turn and talk."

Such prompts initiated students' thinking about different types of patterns, such as repeating patterns. Being asked to turn and talk frequently during the lesson gave all students a chance to participate in the discourse.

- **Connections** and applications to mathematics in the immediate surroundings were made when—at the beginning of the lesson—the teacher asked students to look around the room for patterns. Students applied the concept of pattern to a variety of different objects as they worked with partners to create their own patterns. Also, assigning students to look for patterns at home was resourceful lesson extension.

Two of the dimensions would be described as *medium* by our descriptors, meaning that they match many, but not all, of the high descriptors for that dimension:

- **Explanation** and justification as a dimension gives equal weight to teacher questions and student responses. High quality includes both great questioning by teachers and detailed responses by students. Here, the teacher asked questions during the lesson, but many student answers were brief and failed to demonstrate detailed explanation or justification. More explicit questioning and probing for responses would have enhanced this lesson.
- **Problem solving** in this lesson met some, but not all the descriptors for a high-quality lesson. The concept of pattern was somewhat new to students, and they grappled with the idea of *repeating* as they tried to make their own patterns. When they looked at the number pattern in the ice skating problem, the teacher encouraged more than one approach to solving the problem. However, the focus of the lesson was not on discussing multiple strategies for solving pattern problems. The next step might be for the teacher to give students some challenging number problems and have them discuss ways to arrive at the answers.

Next steps

Focused reflection on your daily practice has the potential to improve mathematics instruction and lead to more high-quality, equitable mathematics instruction for your elementary school students. Consider the following in efforts to incorporate the M-Scan into your future lessons:

1. Decide which one mathematical concept is most important for students to learn on a particular day.
2. Carefully select exercises to help deepen their understanding of that concept.
3. Choose the representations and tools to incorporate into the lesson in order to make the concepts clearer to all learners.
4. Opt for problems that students will address in class, that allow for multiple solution strategies, and that provide high cognitive demand.
5. Think about how to involve students in the conversation and what role they have in the learning process. Be sure that the questions you ask require students to explain and justify.
6. Begin each math lesson by building on what students already know, helping them make connections to prior mathematical knowledge and their daily lives.

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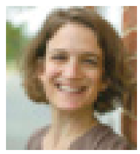


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This dialogue is an excerpt from a model third-grade lesson about patterns.

The following lesson objective was written on chart paper at the start of class:

> Today we will learn to recognize and describe a variety of patterns using concrete objects, numbers, letters, and pictures and extend the patterns using the same or different forms.

The teacher had students read the message and asked them to think of words they recognized from the objective. Next, they turned and talked to a partner about the words. (The teacher's words are in blue text.)

Class, we see patterns everywhere, but sometimes we don't recognize them. A key word here is to recognize a pattern. Let's look around the classroom. What patterns do you recognize?
The calendar.

Can you describe it?
It's a color pattern: purple, yellow, red, purple, yellow, red.

Extend. What will be the next one?
Yellow, red.

When you recognize, it means you know that it is a pattern, and then you describe it, and then you extend and say what the next one will be.
The number line: Even, odd, even, odd, even, odd. Blue, yellow, blue, yellow.

You made two patterns. Let's look at other patterns. Do you see any patterns on this? [*She points to an index card with a pattern*.]
The stars.

What about them? Is there a pattern here?
No.

Who said no? Why not?
Because the stars are not, like, in line. They are just all over the place.

Yes, the stars are everywhere around the space and not in line. What patterns do you see here?
Greatest to least and odd to even.

Is that a pattern? Odd, even, odd, even numbers; that's a pattern. Do you see any pattern here? Get your nine o'clock partner and turn and talk. [*Students turn to their partners and share ideas*.] Who would like to share their thinking?
Two are going the right way, and two are going left: two right, two left.

What do you think? If you agree, put your thumbs up.
I have another idea. The sides go greater, greater, less, less, greater, greater, less, less.

So you make a connection when you see the shirt: "Oh, it's about patterns." [*She offers more examples*.] Let's define *pattern*. Since we recognize, we describe, and we extend the patterns, let's do the definition. What is a pattern? Turn and talk to your partner. If you're ready, put your hands up.
A pattern is a bunch of things put together that repeat over and over.

Let's help each other. Instead of *bunch*, what [*word*] can we use?
A set.

A *pattern* is a set of shapes that repeat over and over again. [*A student writes the new definition on the board*.] Can you whisper this definition to the person next to you?

Now I will set different stations, and I'd like you to find your nine o'clock partner and make a pattern using these objects [*passing a basket of objects for students to select from*].

First, you have to make a pattern. After that, describe it to your partner. Then, ask your partner, "If the pattern … continue[s], what will be next?"

[*The teacher circulates to observe and assist students. She talks with many groups before addressing a pair of students*.] What is the definition of *pattern*? What is repeating over and over again? Extend it, OK?

[*She addresses the larger group again*.] Describe your pattern. Ask your classmates what will be the next object if the pattern will continue. Who would like to be the first to share?
We did this pattern: it's Granny Smith, pear, red apple, Granny Smith, pear, red apple.

If you extend it, what will be next?
This one [*pointing to a Granny Smith apple*].

Another volunteer, please?
We did the first one: yellow, red, two yellows, reds, three yellows, red, four yellows.

He did yellow, red, yellow, yellow, red, yellow, yellow, yellow, red, yellow, yellow, yellow, yellow, red. Is this a pattern? It says a pattern is *a set of shapes that repeats over and over and over again*. Turn and talk.
It's a *growing pattern* because every yellow has one more always after a red.

Do you agree it's a *growing pattern*? Have you heard of this before?
We learned it in second grade.

I will give you this paper, and I'd like you to draw a picture of the word *pattern* and make any patterns here and write the meaning in your own words. [*Students work independently on this task, using words and pictures to demonstrate their understanding of the meaning of pattern*.]

TABLE 2

This table shows the amount of time spent ice-skating.

Day	Time Period
Monday	30 min
Tuesday	45 min
Wednesday	60 min
Thursday	75 min
Friday	90 min
Saturday	?

I noticed you drew a lot of very interesting patterns on your paper. We'll save this for tomorrow and finish during sharing time. For now, I want you to look at this [*pointing to a SmartBoard*]. **This table** [*see* **table 2**] **shows the amount of time spent ice-skating. If the pattern in the table continues, how many minutes will Karen spend practicing on Saturday? What do you think of the table? Do you think it's a pattern?**
'Cause on Monday it has thirty minutes, on Tuesday forty-five, on Wednesday sixty. If you take the first number out, it would be a pattern like zero, five, zero, five.

This is a pattern; she has her own strategy. Do you agree this is a pattern? It is a pattern of minutes. If you cover the tens place [*covering it on the board*]**, it's counting by five.**
It's counting by fifteen.

What would be next?
One hundred five.

You can see patterns not only with colors, shapes, and t-shirts but also in minutes and in everyday life. You see patterns everywhere. What have you learned for today?
We learned that minutes or dates can be patterns.

We learned to describe patterns.

We learned how patterns repeat over and over.

For this weekend, your homework is to look for patterns when you go home since we have learned [that] patterns are everywhere. And then come back on Monday ready to share what you have noticed.