A Tool for Rethinking Teachers' Questioning

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A Tool for Rethinking QUESTIONING

The Cognitive Rigor Matrix is a tool that teachers can use to analyze and reflect on questions and tasks and, in the process, increase the level of rigor.

Teachers'

Amber Simpson, Stefani Mokalled, Lou Ann Ellenburg, and S. Megan Che

The substance of questions has been at the forefront of considerations of discourse since Socrates instituted his gadfly approach. In the last century, Gould (1923) claimed, "As a general rule it is well to avoid all . . . questions which do not stimulate thought. Any question which suggests the answer is worthless" (p. 55). As a "skillful presiding officer of an assembly" (p. 53), Gould proposed that teachers should question students to stimulate reflective thinking, recall principles and form hypotheses, reason independently, and contribute to class discussions. Additionally, Kuhn (2005) argued that students should also develop skills of inquiry and of argument as a way of becoming independent thinkers and learners. These skills are a social activity that should be developed and fostered by teachers through the questions and mathematical tasks posed to students.

NCTM, too, encourages teachers to promote a classroom environment of communication through mathematical discourse that will elicit students' thinking and reasoning beyond that of procedural tasks (NCTM 2000). Finally, teacher questioning processes can play a critical role in addressing the Common Core's Standards for Mathematical Practice, such as forming viable arguments and judging the reasoning of peers (CCSSI 2010).

Walsh and Sattes (2005) point out what educators likely intuitively sense: Teachers, through quality questioning techniques, can transform typical mathematics classrooms into more student-centered, inquiry-based classrooms in which students are thinking and reasoning at high levels. Despite the potential of questioning to increase students' cognitive engagement with mathematics, several studies indicate that the vast majority of classroom questioning hovers at the lower rungs of cognitive demand (Barba and Cardinale 1991; Özerk 2001).

One of many complicated and overlapping factors in the persistence of lower-level teacher questions may be that self-reflection on one's questioning practices can be inaccurate, perhaps limiting a teacher's sense that his or her questioning practices could benefit from modification. For instance, Walsh and Sattes (2005) draw on the study by Susskind (1979) in which teachers self-reported that, on average, they asked approximately 15 questions within a 30-minute time frame. However, once these teachers were observed, it was found that they asked an average of 50.6 questions within a 30-minute time frame, which equates to approximately 1–2 questions being posed by the teachers every minute. The high frequency of teacher questions posed is likely an indication that most of these questions are at low cognitive levels; otherwise, students would tend to take more time than 1–2 minutes on questions requiring higher quality of thought.

In this article, we present a tool, the Cognitive Rigor Matrix (CRM; Hess et al. 2009), as a means to analyze and reflect on the type of questions posed by mathematics teachers. This tool is intended to promote and develop higher-order thinking and inquiry through the use of purposeful questions and mathematical tasks. We illustrate the utility of the CRM by examining one teacher's use of questions during classroom discussions. We also include this teacher's reactions after seeing the result of the analysis of her questioning techniques, as well as her thought process of using the CRM to reframe her questions through short classroom excerpts. On the basis of our experience with this matrix, we have found that it is useful and might be of interest to classroom teachers, instructional coaches, and professional development providers who wish to modify their classroom questioning techniques.

COGNITIVE RIGOR MATRIX

One teacher had this to say about questioning in the classroom:

> Wow, we have been working with Bloom's for so long and think that because we have made it to the create level we are doing it right. However, by looking at this Matrix, we could be creating and still be at DOK [depth of knowledge] level one! (Tiffany Arnold, mathematics teacher, personal communication to author, November 21, 2013)

The CRM (see **table 1**) is a two-dimensional structure that incorporates the cognitive dimension of the revised version of Bloom's Taxonomy

Table 1 The Cognitive Rigor Matrix incorporates Webb's levels of Depth of Knowledge and the cognitive dimensions of the Revised Bloom's Taxonomy.

	Webb's Depth of Knowledge			
Revised Bloom's Taxonomy	**DOK Level 1 (DOK-1): Recall and Reproduction**	**DOK Level 2 (DOK-2): Basic Skills and Concepts**	**DOK Level 3 (DOK-3): Strategic Thinking and Reasoning**	**DOK Level 4 (DOK-4): Extended Thinking**
Remember (Bloom 1)	Recall, recognize, and locate basic facts, ideas, and principles			
Understand (Bloom 2)	Describe/explain how (explain the steps required for specified algorithms)	Specify and explain relationships (explain why the procedure for a specified algorithm is reasonable)	Explain strategies and reasoning processes for solving tasks for which procedures have not been specified	Explain how concepts or ideas specifically relate to other content domains or concepts
Apply (Bloom 3)	Apply an algorithm or formula	Solve routine problems applying multiple concepts or decision points	Use concepts to solve nonroutine problems	Select or devise an approach among many alternatives to solve a novel problem
Analyze (Bloom 4)	Retrieve information from a table or graph to answer a question	Compare and contrast figures or data	Generalize a pattern	Gather, analyze, and organize information
Evaluate (Bloom 5)			Verify reasonableness of results	Draw and justify conclusions
Create (Bloom 6)	Brainstorm ideas, concepts, or perspectives related to a topic or concepts	Generate conjectures or hypotheses based on observations or prior knowledge	Formulate an original problem	Design a model to inform and solve real-world, complex, or abstract situations

Source: Adapted from Hess et al. (2009)

(Anderson and Krathwohl 2001) on one axis and Webb's Depth of Knowledge (DOK) on another axis (Hess et al. 2009). Within the table, we have included one example (Hess et al. 2009) in each cell. With this matrix, questions and tasks can be classified using two dimensions (type of thinking and depth of knowledge) rather than one hierarchy of categorical levels. As illustrated by the quote above, questions and tasks that may be categorized at a lower level along one axis may be considered as a higher level along the other axis. In some instances, it is important to consider what action or behavior follows the verb. Consider the following instance:

- *Describe* the rule to convert a decimal to a percent.
- *Describe* an example and a nonexample of a polygon.
- *Describe* the data represented in the graphs and support statements and/or conclusions.
- *Describe* the most appropriate dimensions for a box to hold 8 golf balls.

The term *describe* is classified in a lower level (remember) in Bloom's taxonomy. As can be seen in the table, it is more the content of the question or task posed than any particular verb that determines complexity. Likewise, the same argument may apply to "why" and "how" questions to elicit student descriptions and explanations. To determine the appropriate cell, one must consider what is being explained. Take, for example, "Explain how you solved the equation $4x = 28$." We would code this as DOK-1, Bloom 2 because the teacher asked a student to explain the specific step or operation that he or she performed as part of applying an algorithm, particularly if that algorithm had just been explicitly taught to the student. In contrast, if a teacher asked a student to explain his or her strategy for a task that required the student to devise or select a strategy, we would code that as DOK-3, Bloom 2 because the teacher is asking for the student's strategic thinking and reasoning in his or her explanation.

To illustrate our procedure for classifying questions and tasks in the CRM, consider an instance when a teacher asks her students to solve a one-step equation, such as $x + 8 = 3$. After attempting to place this question or task in the CRM, the reader is likely to ask whether students have already been introduced to strategies for solving similar tasks or not.

For this instance we will assume, as is almost always the case in our observations, that students have been instructed on a specific procedure for solving similar equations. Thus, this question or task would be placed in the DOK-1, Bloom 3 cell within the matrix (Hess et al. 2009). This item is ranked as DOK-1 because it does not require students to make a decision about a strategy for approaching the problem; students in this case are expected to carry out an algorithm. It is ranked as Bloom's "apply" category because students are expected to use a procedure in a given situation. To increase the cognitive rigor of this task, students could be asked to describe a real-world situation in which they would use this equation to solve a problem. This type of task will reside in DOK-3, Bloom 2 because the students must reason through the meaning of this equation to develop a real-world phenomenon modeled by the equation. It is classified in Bloom's "understand" category because the students must understand the concept to describe this real-world situation. However, the students may also apply Bloom 3 procedures to solve this problem if they do determine the value of x within their descriptions.

Another way to increase the cognitive level would be to have students create their own real-world situation that can be modeled with a linear equation (without giving them an equation). This task will be DOK-3, Bloom 6 because, again, students must reason through the concept of a linear equation to think strategically and find a problem. It is a "create" problem in Bloom's taxonomy because it requires students to design an original problem on the basis of their understanding of linear equations. Therefore, a task that is originally lower level can be revised to increase its cognitive rigor along both dimensions of the matrix.

CLASSROOM CONTEXT AND PROCESS

We (*the authors*) are working together as part of a larger study that is currently examining the impact of single-sex public educational environments on mathematical classrooms. Ms. Jenkins, a seventh-grade mathematics teacher, has been teaching for eight years in the public school system and expressed an interest in learning more about classroom discourse and questioning. In conjunction with the research project, some of Jenkins's classes were videorecorded. One lesson in particular, which we discuss in this article, involved students manipulating 1-inch connecting cubes to determine the formula for the volume of a rectangular prism and the volume of a cube.

To gain a better understanding of Jenkins's questioning practices, we used the CRM and categorized each question and mathematical task (imperative statement) that she asked and taught during one instructional day. We decided to include imperative statements *and* explicit questions because the intent of both forms of questioning was the same: The teacher was seeking information, confirmation, or agreement (Stivers and Enfield 2010). For instance, "figure out the volume of a $3 \times 3 \times 3$ figure" is posed in the form of a statement, yet the teacher is seeking an answer.

Further, we excluded teacher questions that she answered herself; we considered only questions and imperative statements that resulted in student responses. After categorizing each question and imperative statement within one of the cells, we calculated the percentage of the total for each cell and displayed the results in a cognitive rigor density plot (Hess et al. 2009). As can be seen in **table 2**, the majority of the questions were placed into the DOK-1, Bloom 1 cell of the CRM, which indicates that students across three class periods were primarily asked to recall and state basic facts and information related to the volume of various figures.

When presented with the results of the density plot, Jenkins's initial response was to gasp at the empty cells within the matrix, particularly, Bloom's cognitive level "apply." This concern stemmed from her misperception that she consistently required students to apply the information she taught. Furthermore, she noted how easy it was to become comfortable with her role as a teacher and not reflect and improve on her

Bloom's and Webb's

Descriptors of Bloom's dimensions and Webb's levels are given below for a quick reference while reading.

Revised Bloom's Taxonomy
- Remember
- Understand
- Apply
- Analyze
- Evaluate
- Create

Webb's Depth of Knowledge
Level 1: Recall and reproduction
Level 2: Basic skills and concepts
Level 3: Strategic thinking and reasoning
Level 4: Extended thinking

Table 2 The Cognitive Rigor Density Plot shows the categorized percentage of questions from the lesson on volume.

Revised Bloom's Taxonomy	Webb's Depth of Knowledge			
	DOK-1	DOK-2	DOK-3	DOK-4
Bloom 1	55%			
Bloom 2	20%	5%	10%	
Bloom 3	5%	5%		
Bloom 4				
Bloom 5				
Bloom 6				

Source: Adapted from Hess et al. (2009)

instructional practices. With the transition to the Common Core State Standards, Jenkins acknowledged that she would need to challenge students to think by incorporating mathematical questions and tasks that span all levels of Bloom's taxonomy and Webb's DOK. She also emphasized a desire to push her students to be learners who are more independent, who will grapple with mathematical ideas and concepts without asking for guidance, and who will develop the skills of inquiry (Kuhn 2005).

Using one transcript from the lesson on volume, we worked with Jenkins to apply the CRM to reflect on and rethink her questions and tasks. **Table 3** presents part of the transcript

Table 3 Students were asked to revise the formula for the volume of a rectangular prism.

Transcript	Hypothetical Scenario
T: Let's talk about a formula for this. What do you think it would be? [DOK-1, Bloom 2] *S:* Length × width × height? *T:* Length × width ×. I want you to set it on its 2 by 3. What's the length? [DOK-1, Bloom 1] *S:* 3 units *T:* What's the width? [DOK-1, Bloom 1] *S:* 2 units *T:* What's the height? [DOK-1, Bloom 1] *S:* 4 *T:* What can we do here? [DOK-1, Bloom 1] *S:* Multiply *T:* What do we get? [DOK-1, Bloom 3] *S:* 24 *T:* If I only do this part right here, I have length × width. What does that equal? [DOK-1, Bloom 1] *S:* Area *T:* What do we have to do in this shape to get our volume when we compare it to the area? [DOK-2, Bloom 4]	*T:* Let's analyze the figure and see if we can discover a way to help us find the formula for the volume. [DOK-2, Bloom 2] *S:* Length × width × height? *T:* Length × width × height. Set your figure down and determine the dimensions of your figure [dimensions may vary]. [DOK-1, Bloom 3] *S:* The length is 3 units, the width is 2 units, and the height is 4 units. *T:* Now that we have the dimensions, remind me of the process that we need to use to solve for the volume. [DOK-2, Bloom 3] *S:* We have to multiply. So, 3 × 2 is 6, and 6 × 4 is 24. *T:* Your solution was 24. Can you interpret the meaning of that answer? [DOK-2, Bloom 2] *S:* 24 is the volume or the number of blocks in the figure. *T:* If 24 is the volume of the figure, what would it mean if you only multiplied two of the numbers, like 3 × 2 instead of 3 × 2 × 6? [DOK-2, Bloom 1] *S:* If I multiplied 3 and 2, that would be the area. *T:* Let's examine some other answers. Explain why your dimensions are not all the same, but why everyone came up with the same solution anyway. [DOK-3, Bloom 2] *S:* The numbers for the length and the width and the height depends on how the figure is sitting on the table, but we're still multiplying the same numbers, so we still all get the same answer.

Table 4 With this task, students used blocks to discover the proof of the Pythagorean theorem.

Transcript	Hypothetical Scenario
T: It should be easy, once you get it together, to see which one is the biggest one. Alright, so this 25 is the biggest one. So some of you were arguing about which one was the hypotenuse. The hypotenuse is going to be the biggest one. This is an easy way to see that that's the biggest one. Okay. A visual of how many it takes to make that up. Now let's go a little bit deeper. How many squares total did we need to make that 3×3? [DOK-1, Bloom 1] *S:* Nine plus sixteen *T:* It would be nine. How many would we need to make . . . ? [DOK-1, Bloom 1] *S:* Sixteen. Plus, equals 25. *T:* What's 9 + 16? [DOK-1, Bloom 2] *S:* 25 *T:* So it took how many blocks to build a and b? [DOK-1, Bloom 2] *S:* 25 *T:* It took how many blocks to build the other one? [DOK-1, Bloom 1] *S:* 25 *T:* So that's why this works. Because when you have these two squared and added. This one squared and added. They equal the exact same thing. So this side, if you count your two legs. You count all the squares that you used to make up your two legs, and that's on one side. Then count all the squares that are in the 5×5; it should be the exact same number. And that number should be what? [DOK-1, Bloom 1] *S:* 25	*T:* Determine a relationship between the number of blocks in the squares that you created. [DOK-2, Bloom 2] *S:* If you add the blocks from the smaller squares, you get 9 plus 16, which is 25, and that's the same number of blocks in the big square. *T:* So that's why it works. You squared these two and added, which is the same as this one squared. And do you think this relationship will be true for all triangles? [DOK-2, Bloom 2] *S:* Yes. *T:* Why? [DOK-1, Bloom 2] *S:* I don't know. *T:* So let's try an isosceles triangle with side lengths 3, 3, 6. Will the relationship be the same? Why or why not? [DOK-2, Bloom 2] *S:* No, because adding 3^2 to 3^2 does not equal 6^2. *T:* Can you elaborate a little more? [DOK-1, Bloom 2] *S:* Adding the square of the two smaller sides, basically 9 + 9, is not the same as the square of the longer side or 36. *T:* Okay, let's try a few more examples: (e.g., 4–7–8; 7–7–7; 4–10–10; 9–40–41; 6–12–$6\sqrt{5}$) Your task is to make a conjecture based on your findings. [DOK-3, Bloom 4]

in which students were initially asked to build a $2 \times 3 \times 4$ figure. The left-hand column represents the original transcript, with the CRM cell identified after each question posed. The right-hand column represents a hypothetical scenario based on our conversation with Jenkins. Using the CRM, she described how this experience made her more cognizant of including higher-order thinking skills and rigorous questions to her daily lessons.

Because the CRM is a recently formulated framework and its use in analyzing classroom questions and tasks is not widespread, we offer here our process of reasoning for a few of the questions from **table 3** and their placement in the matrix. We acknowledge that others may code questions differently, based on their mathematical experiences and their reading of the short scenario. Indeed, the process of deliberating question placement within the matrix can be at least as important as the final placement of any particular question within the matrix because this deliberation is a means by which we can think deeply about the intent and implementation of our questioning practices.

In our experience, a large majority of classroom questions is easy to place within the matrix, and we can have important and meaningful discussions about the few questions that remain. The question "What is the width?" is placed in DOK-1, Bloom 1. This question required the students to recall or count the number of 1-inch cubes needed to construct the width of the figure. Additionally, the question "What do we get?" is placed in cell DOK-1, Bloom 3 because students were asked to substitute the values of the length, width, and height of the figure into the volume formula, to then follow a specified order of operations rule to evaluate the expression.

And last, the question "What do we have to do in this shape to get our volume when we compare it to the area?" is placed in cell DOK-2, Bloom 4 because students were challenged to extend the process of multiplication to find area into a process of multiplication to calculate volume. Consider one of the questions from the hypothetical scenario, "Let's analyze the figure and see if we can discover a way to help us find the formula for the volume." This question was coded DOK-2, Bloom 2 because students were asked to make a basic inference based on a concrete model, as opposed to being asked, "What is the volume formula?" (DOK-1, Bloom 1).

A two-dimensional matrix for categorizing the cognitive demand of questions and tasks is a novel technique for many teachers and teacher educators. To facilitate the readers' familiarity with this technique, we have included another scenario **(table 4)**. You might try to place imperative statements and questions within the CRM individually, with a colleague, your math team, or an instructional coach. We find that the process of modifying statements and questions to reach higher cognitive levels tends to follow quite naturally from the process of classifying the original questions. We have included our coding of the questions using the CRM, as well as our discussion on the scenario, in the right-hand column. This is just one scenario in myriad possible scenarios. Note how changing one question to increase the rigor and complexity of the task has the potential to alter the classroom discussion.

As a way to further illustrate our implementation of the CRM, we elaborate on our reasoning for classifying the questions. The teacher's question, "What's 9 + 16?" was placed in cell DOK-1, Bloom 2 because students were asked to recall addition facts (DOK-1) and understand how to evaluate an expression (Bloom 2). We did not code this question as Bloom 1 because the addition algorithm required students to regroup; a skill that may or may not be mentally mastered.

Consider a few of the questions from the hypothetical scenario: "Let's try an isosceles triangle with side lengths 3, 3, 6. Will the relationship be the same? Why or why not?" Because these two questions ask students to look for a relationship, more specifically to confirm or disconfirm the earlier relationship based on the Pythagorean theorem (i.e., 9 + 16 = 25), and to begin considering an example or nonexample, this question was coded as DOK-2, Bloom 2. At this point, students are making a conjecture based on two examples. Yet the task "make a conjecture based on your findings" from a few more examples was placed in DOK-3, Bloom 4 because students were asked to analyze and draw conclusions based on examples and nonexamples. We also acknowledged that students might provide more than one response. As one more example, consider the question, "Can you elaborate a little more?" This question was placed in DOK-1, Bloom 2 because, in this instance, the student was asked to evaluate two exponential terms and restate her or his prior explanation.

SUGGESTIONS

Many of the observations from the question analyses naturally sparked discussions of strategies to improve questioning techniques, such as these:

1. Find a peer or form a mathematics club to observe one another's lessons focusing on and writing down the questions and tasks posed. By the same token, videorecord or audiorecord a lesson to analyze individually or with others. Several Internet resources, such as the NCTM, the Teaching Channel, and the TIMSS, have videos that can be analyzed and discussed.
2. Write out questions before teaching that target a variety of cells within the matrix. Have the questions on hand during the lesson for easy access. The construction of these questions may be based on anticipating students' solutions to mathematical tasks (Smith and Stein 2011). These and similar questions can also be used on quizzes, unit exams, and other summative assessments.
3. Role-play different scenarios, intently focusing on the questions and tasks posed, with colleagues before a lesson is taught. Also, as a way to promote a higher cognitive level of learning, practice providing one another enough time to answer questions (Tobin 1987).
4. When providing feedback to students' responses and solutions, comment on the process and not the product or the person (Johnston 2012). Doing so can lead to richer, more complex questions and classroom discussions.

(RE)EVALUATE THE ROLE OF QUESTIONS

Questions can, so to speak, make or break a classroom discussion. Given the transition to CCSSM and the associated assessments, (re)evaluating the role and use of questions as we engage students in thinking and reasoning

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mathematically is a timely topic. In our experience, the CRM provided a meaningful, revealing lens through which to analyze Jenkins's questioning strategies. For our team, which includes Jenkins, the CRM has been a concrete tool to help make sense of how we construct questions and has provided a focal point for reflection on our teaching. The expansion of the familiar Bloom's taxonomy into a two-dimensional matrix incorporating a range of depth has helped us open up space for viewing, with a sharper focus, at the questions we ask as we seek to engage students in rigorous mathematical thinking.

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Any thoughts on this article? Send an email to ***mtms@nctm.org***.—*Ed*.

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