What exactly do “fewer, clearer, and higher standards” really look like in the classroom? Using a cognitive rigor matrix to analyze curriculum, plan lessons, and implement assessments

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Abstract

With the ever-increasing call for more rigorous curriculum, instruction, and assessment in the United States, the National Governors Association and the Council of Chief State School Officers are aiming to define the rigorous skills and knowledge that students need in order to succeed academically in college-entry courses and in workforce training programs (Glod, 2009). The proposed Common Core Standards will require high-level cognitive demand, such as asking students to demonstrate deep conceptual understanding through the application of content knowledge and skills to new situations. Using two widely accepted measures of describing cognitive rigor — Bloom's Taxonomy of Educational Objectives and Webb’s Depth-of-Knowledge Levels — this article defines cognitive rigor and presents a matrix that integrates these models as a strategy for analyzing instruction and influencing teacher lesson planning. Using Hess’ Cognitive Rigor Matrix (CRM), a density plot illustrates how the preponderance of curricular items (e.g., assignment questions and problem solving tasks) might align to cells in the matrix. Research results applying the matrix in two states’ large-scale collection of student work samples are presented, along with a discussion of implications for curriculum planning in order to cultivate twenty-first century skills.

Beginning with Bloom

In 1956, a group of educational psychologists headed by Benjamin Bloom developed a classification of levels of intellectual behavior important in learning. Bloom created this taxonomy for categorizing the levels of abstraction of questions that commonly occur in educational settings. Using these levels for analysis, Bloom found that over 95% of test questions students encounter at the college level required them to think only at the lowest possible level: the recall of information. Bloom’s committee identified three domains of educational activities: cognitive (*knowledge*), affective (*attitude*), and psychomotor (*skills*). Within the cognitive domain, which is tied directly to mental skills, Bloom identified a hierarchy of six levels that increased in complexity and abstraction – from the simple recall of facts, *knowledge*, to the highest order of thinking, *evaluation*. In practice, educators assigned Bloom's Taxonomy levels according to the main action verb associated with a level in the taxonomy. For example, examining the meaning of a metaphor and categorizing geometric shapes would both align to Bloom's Taxonomy, *Analysis* level. While educators have found such verb cues of Bloom’s Taxonomy levels to be useful in guiding teacher questioning, verbs often appear at more than one level in the taxonomy (e.g., *appraise, compare, explain, select, write*); and often the verb alone is inadequate for determining the actual cognitive demand required to understand the content addressed in a test question or learning activity. (See Table 1.)

Building upon Bloom’s early work, many educational and cognitive psychologists have since developed various schemas to describe the cognitive demand for different learning and assessment contexts. In 2001, Anderson, Krathwohl, et al. presented a structure for rethinking Bloom’s Taxonomy. Whereas the original taxonomy possessed one dimension, the revised taxonomy table applied two dimensions—cognitive processes *and* knowledge. The cognitive processes resemble those found in the original taxonomy, but placement on the taxonomy continuum has changed slightly (e.g., evaluation no longer resides at the highest level) and descriptions have been expanded and better differentiated for analyzing educational objectives. The revised descriptors consider both the processes (the verbs) and the knowledge (the nouns) used to articulate educational objectives. This restructuring of the original taxonomy recognizes the importance of the interaction between the content taught — characterized by factual, conceptual, procedural, and metacognitive knowledge — and the thought processes used to demonstrate learning.

Table 1: A Comparison of Descriptors: Bloom's Original Taxonomy and the Revised Bloom's Taxonomy Cognitive Process Dimensions

Bloom's Taxonomy (1956)	**The Revised Bloom Process Dimensions** (2005)
Knowledge Define, duplicate, label, list, memorize, name, order, recognize, relate, recall, reproduce, state	**Remember** Retrieve knowledge from long-term memory, recognize, recall, locate, identify
Comprehension Classify, describe, discuss, explain, express, identify, indicate, locate, recognize, report, restate, review, select, translate	**Understand** Construct meaning, clarify, paraphrase, represent, translate, illustrate, give examples, classify, categorize, summarize, generalize, infer a logical conclusion (such as from examples given), predict, compare/contrast, match like ideas, explain, construct models (e.g., cause-effect)
Application Apply, choose, demonstrate, dramatize, employ, illustrate, interpret, practice, schedule, sketch, solve, use, write	**Apply** Carry out or use a procedure in a given situation; carry out (apply to a familiar task), or use (apply) to an unfamiliar task
Analysis Analyze, appraise, calculate, categorize, compare, criticize, discriminate, distinguish, examine, experiment, explain	**Analyze** Break into constituent parts, determine how parts relate, differentiate between relevant-irrelevant, distinguish, focus, select, organize, outline, find coherence, deconstruct (e.g., for bias or point of view)
Synthesis Rearrange, assemble, collect, compose, create, design, develop, formulate, manage, organize, plan, propose, set up, write	**Evaluate** Make judgments based on criteria, check, detect inconsistencies or fallacies, judge, critique
Evaluation Appraise, argue, assess, choose, compare, defend, estimate, explain, judge, predict, rate, core, select, support, value, evaluate	**Create** Put elements together to form a coherent whole, reorganize elements into new patterns/structures, generate, hypothesize, design, plan, construct, produce for a specific purpose

Webb's Depth-of-Knowledge (DOK) Levels

Depth of knowledge forms another important perspective of cognitive complexity. Probably the best-known work in the area of depth of knowledge is that of Norman Webb (1997, 1999). Webb's work has forced states to rethink the meaning of test alignment to include both the content assessed in a test item and the intended cognitive demand, or the depth to which we expect students to demonstrate understanding of that content. In other words, the complexity of both the content (e.g., simple vs. complex data displays; interpreting literal vs. figurative language) and the task required (e.g., solving routine vs. non-routine problems) are used to determine DOK levels. Webb describes his depth-of-knowledge levels as "nominative" rather than as a taxonomy, meaning that DOK levels name (or describe) four different and deeper ways a student might interact with content (2002).

Webb's Depth-of-Knowledge Levels

DOK-1 – **Recall & Reproduction** - Recall of a fact, term, principle, concept, or perform a routine procedure
DOK-2 - **Basic Application of Skills/Concepts** - Use of information, conceptual knowledge, select appropriate procedures for a task, two or more steps with decision points along the way, routine problems, organize/display data, interpret/use simple graphs
DOK-3 - **Strategic Thinking** - Requires reasoning, developing a plan or sequence of steps to approach problem; requires some decision making and justification; abstract, complex, or non-routine; often more than one possible answer
DOK-4 - **Extended Thinking** - An investigation or application to real world; requires time to research, problem solve, and process multiple conditions of the problem or task; non-routine manipulations, across disciplines/content areas/multiple sources

Identifying the DOK levels of questions in tests or class assignments can help to articulate how deeply students must understand the related content to complete the necessary tasks. Unlike Bloom's Taxonomy, Webb's model dictates that depth-of-knowledge levels do not necessarily correlate to the commonly understood notion of "difficulty." That is, an activity that aligns to a particular level is not always "easier" than an activity that aligns to a DOK level above it. For example, a DOK-1 activity might ask students to restate a simple fact or a much more abstract theory, the latter being much more difficult to memorize and restate. Neither of these DOK-1 tasks asks for much depth of understanding of the content. On the other hand, greater depth is required to explain how or why a concept or rule works (DOK-2), to apply it to real-world phenomena with justification or supporting evidence (DOK-3), or to integrate a given concept with other concepts or other perspectives (DOK-4).

Interpreting and assigning intended DOK levels to both the standards and the related assessment items are now essential requirements in any alignment analyses. Webb's depth-of-knowledge levels have been applied across all content areas (Hess, 2004, 2005a, 2005b, 2006a, 2006b; Petit & Hess, 2006) and many states and districts utilize the concept of depth of knowledge to designate the depth and complexity of state standards in order to align the state's large-scale assessments or to revise existing standards to achieve higher cognitive levels for instruction. Consequently, teachers need to develop the ability to design instruction, and create units of study/curriculum and classroom assessments for a greater range of cognitive demand.

Cognitive Rigor and the CR Matrix

Although related through their natural ties to the complexity of thought, Bloom's Taxonomy and Webb's depth-of-knowledge differ in scope and application. Bloom's Taxonomy categorizes the cognitive skills required of the brain to perform a task, describing the "type of thinking processes" necessary to answer a question. Depth of knowledge, on the other hand, relates more closely to the depth of content understanding and scope of a learning activity, which manifests in the skills required to complete the task from inception to finale (e.g., planning, researching, drawing conclusions). Both the thinking processes and the depth of content knowledge have direct implications in curricular design, lesson delivery, and assessment development and use.

While there is no simple one-to-one correspondence between these complexity schemas to articulate cognitive rigor, the superposition of Bloom's Taxonomy and Webb's Depth-of-Knowledge Levels was originally expressed in matrix form by Hess (Hess, 2006, 2006b) for use in states where the conversation about cognitive complexity as part of the test design and item development process was just beginning. The CR matrix has been helpful in explaining to teachers how the two conceptual models—Bloom's Taxonomy and Webb's DOK levels —are alike, yet different (Table 2). More importantly, the CR matrix allows educators to examine the depth of understanding required for different tasks that might seem at first glance to be at comparable levels of complexity. Finally, the CR matrix allows educators to uniquely categorize and examine selected assignments/ learning activities that appear prominently in curriculum and instruction. For example, the rote completion of single-step mathematical routines, often derided by the moniker "plug and chug," lies positioned within the (DOK-1, Bloom-3) or the (1,3) cell of the CR matrix. Using the CR matrix to plot typical mathematics assignments from a unit of study, a teacher might discover to what extent this level of cognitive rigor is being assessed compared to (DOK-3, Bloom-3) or the (3,3) cell of the CR matrix, using strategic thinking/reasoning (DOK-3) and application (Bloom-3). When used to plot multiple assignments over time, the CR matrix can graphically display a unique view of instructional emphasis and ultimately reveal the focus of learning within a classroom, a grade level, or a school system.

Table 2: Hess' Cognitive Rigor Matrix with Curricular Examples: Applying Webb's Depth-of-Knowledge Levels to Bloom's Cognitive Process Dimensions

Bloom's Revised Taxonomy of Cognitive Process Dimensions	**Webb's Depth-of-Knowledge (DOK) Levels**			
	Level 1 Recall & Reproduction	**Level 2 Skills & Concepts**	**Level 3 Strategic Thinking/ Reasoning**	**Level 4 Extended Thinking**
Remember Retrieve knowledge from long-term memory, recognize, recall, locate, identify	Recall, recognize, or locate basic facts, ideas, principles Recall or identify conversions: between representations, numbers, or units of measure Identify facts/details in texts			
Understand Construct meaning, clarify, paraphrase, represent, translate, illustrate, give examples, classify, categorize, summarize, generalize, infer a logical conclusion (such as from examples given), predict, compare/contrast, match like ideas, explain, construct models	Compose & decompose numbers Evaluate an expression Locate points (grid/, number line) Represent math relationships in words pictures, or symbols Write simple sentences Select appropriate word for intended meaning Describe/explain how or why	Specify and explain relationships Give non-examples/examples Make and record observations Take notes; organize ideas/data Summarize results, concepts, ideas Make basic inferences or logical predictions from data or texts Identify main ideas or accurate generalizations	Explain, generalize, or connect ideas using supporting evidence Explain thinking when more than one response is possible Explain phenomena in terms of concepts Write full composition to meet specific purpose Identify themes	Explain how concepts or ideas specifically relate to other content domains or concepts Develop generalizations of the results obtained or strategies used and apply them to new problem situations
Apply Carry out or use a procedure in a given situation; carry out (apply to a familiar task), or use (apply) to an unfamiliar task	Follow simple/routine procedure (recipe-type directions) Solve a one-step problem Calculate, measure, apply a rule Apply an algorithm or formula (area, perimeter, etc.) Represent in words or diagrams a concept or relationship Apply rules or use resources to edit spelling, grammar, punctuation, conventions	Select a procedure according to task needed and perform it Solve routine problem applying multiple concepts or decision points Retrieve information from a table, graph, or figure and use it solve a problem requiring multiple steps Use models to represent concepts Write paragraph using appropriate organization, text structure, and signal words	Use concepts to solve non-routine problems Design investigation for a specific purpose or research question Conduct a designed investigation Apply concepts to solve non-routine problems Use reasoning, planning, and evidence Revise final draft for meaning or progression of ideas	Select or devise an approach among many alternatives to solve a novel problem Conduct a project that specifies a problem, identifies solution paths, solves the problem, and reports results Illustrate how multiple themes (historical, geographic, social) may be interrelated
Analyze Break into constituent parts, determine how parts relate, differentiate between relevant-irrelevant, distinguish, focus, select, organize, outline, find coherence, deconstruct (e.g., for bias or point of view)	Retrieve information from a table or graph to answer a question Identify or locate specific information contained in maps, charts, tables, graphs, or diagrams	Categorize, classify materials Compare/ contrast figures or data Select appropriate display data Organize or interpret (simple) data Extend a pattern Identify use of literary devices Identify text structure of paragraph Distinguish: relevant-irrelevant information; fact/opinion	Compare information within or across data sets or texts Analyze and draw conclusions from more complex data Generalize a pattern Organize/interpret data: complex graph Analyze author's craft, viewpoint, or potential bias	Analyze multiple sources of evidence or multiple works by the same author, or across genres, or time periods Analyze complex/abstract themes Gather, analyze, and organize information Analyze discourse styles
Evaluate Make judgments based on criteria, check, detect inconsistencies or fallacies, judge, critique			Cite evidence and develop a logical argument for concepts Describe, compare, and contrast solution methods Verify reasonableness of results Justify conclusions made	Gather, analyze, & evaluate relevancy & accuracy Draw & justify conclusions Apply understanding in a novel way, provide argument or justification for the application
Create Reorganize elements into new patterns/structures, generate, hypothesize, design, plan, construct, produce	Brainstorm ideas, concepts, or perspectives related to a topic or concept	Generate conjectures or hypotheses based on observations or prior knowledge	Synthesize information within one source or text Formulate an original problem, given a situation Develop a complex model for a given situation	Synthesize information across multiple sources or texts Design a model to inform and solve a real-world, complex, or abstract situation

Research Results Applying the Hess CR Matrix

In two recent large-scale studies of the enacted (or taught) mathematics and English language arts curricula, teachers from 200 Nevada and Oklahoma public schools submitted over 200,000 samples of student work, which encompassed homework samples, tests, quizzes, and worksheets, completed during the period from February – May, 2008 (The Standards Company LLC, 2008a, 2008b). Using a process developed by The Standards Company LLC, curriculum specialists analyzed: (a) each item on each work sample for the Bloom's Taxonomy levels needed to formulate an adequate response to the prompt; and (b) the overall depth-of-knowledge of each content-specific assignment. The analysts then assigned to each collected work sample the highest Bloom's Taxonomy level appearing on the assignment in addition to its overall depth-of-knowledge level.

The CR density plots in Figure 1 illustrate some sample results for the two studies, relying on the same two-dimensional layout as the CR matrix shown in Table 2, but incorporating the percentage of assignments as a color shade. In this sense, the reader can liken student work to semi-transparent sheets stacked vertically on each cell of the appropriate CRM cell. As the stack increases in height it becomes more opaque and, therefore, darkens. (The studies encompass hundreds of such plots, disaggregated according to grade level, subject area/course, socioeconomic status, etc. The two plots shown here are cumulative examples for each subject area.)

Results for English language arts indicate a preponderance of assignments correlating to the (DOK-2, Bloom-2) cell of Cognitive Rigor. Mathematics assignments, on the other hand, sampled the (DOK-1, Bloom-3) cell to a greater extent (as shown in Fig. 1). Examples of assignments correlating to the lowest level of depth of knowledge and the “apply-level” of Bloom's Taxonomy included one-step solutions of algebraic equations, non-rote multiplication, and long division. Although assignments associated with the (1,3) cell are necessary for students to practice their numeracy and fluency skills in mathematics, the result nonetheless may point to an over-reliance on instructional activities corresponding to straightforward applications of learned or routine steps. This emphasis would not prepare students for non-routine applications or transfer of the same mathematics skills.

The reader should note that the collection period for the entirety of both studies spanned roughly three months, but this only included five consecutive days at each school site. For this reason, the analysis of assignments is likely to have failed to capture instances of DOK-4 activities, which typically require multiple class sessions to complete.

English Language Arts Grade 3

Rows: Revised Bloom's Taxonomy; Columns: Depth of Knowledge

	1	2	3	4
1	26%	3.0%		
2	9.2%	29%	1.8%	
3	13%	8.6%	0.3%	
4	0.1%	5.5%	0.3%	
5		0.3%		
6	0.1%	2.0%	1.0%	

Mathematics Grade 3

Rows: Revised Bloom's Taxonomy; Columns: Depth of Knowledge

	1	2	3	4
1	37%			
2	18%	2.0%		
3	28%	8.3%	0.1%	
4	1.8%	6.2%	0.3%	
5				
6	0.3%	0.6%	0.4%	

Figure 1: Density plots comparing the cognitive rigor of the English language arts and mathematics enacted curriculum (The Standards Company LLC 2008a, The Standards Company LLC 2008b). To generate the results shown, student work was collected from 205 schools across two states. Although all public school grade levels were analyzed, only grade 3 is shown here. The English language arts data corresponds to 12,060 samples of student work; 8,428 for mathematics.

Discussion

One conclusion the researchers have drawn from this work is that both measures of cognitive complexity can serve useful purposes in education reform at the state level (standards development and large-scale assessment alignment) and at the school and classroom levels (lesson design and teaching and assessment strategies). Because cognitive rigor encompasses the complexity of content, the cognitive engagement with that content, and the scope of the planned learning activities, the CR matrix has significant potential to enhance instructional and assessment practices at the classroom level. Superimposing the two cognitive complexity measures produces a means of analyzing the emphasis placed on each intersection of the matrix in terms of curricular materials, instructional focus, and classroom assessment.

Ensuring that curriculum is aligned to “rigorous” state content standards is, in itself, insufficient for preparing students for the challenges of the twenty-first century. Current research on the factors influencing student outcomes and contributing to academic richness supports the concept that learning is optimized when students are involved in activities that require complex thinking and the application of knowledge. Expert teachers provide *all* students with challenging tasks and demanding goals, structure learning so that students can reach high goals, and know how to enhance both surface and deep learning of content (Hattie, 2002). Students learn skills and acquire knowledge more readily when they understand concepts more deeply, recognize their relevance, and can transfer that learning to new or more complex situations. Transfer is more likely to occur when learners have developed deep understanding of content and when initial learning focuses on underlying principles and cause-effect relationships (NRC, 2001).

As educators become more skilled at recognizing the elements and dimensions of cognitive rigor and analyzing its implications for instruction and assessment, they can provide learning opportunities that benefit all students, across all subject areas and grade levels. In essence, the role of a school system is to prepare students by providing them with an aligned curriculum with differentiated emphasis on each of the four depth-of-knowledge levels. The cognitive rigor matrix can serve as a constant reminder to educators that students need exposure to novel and complex activities every day.

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References Cited

Anderson, L., Krathwohl, D., Airasian, P., Cruikshank, K., Mayer, R., Pintrich, P., Raths, J., & Wittrock, M. (Eds) (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Addison Wesley Longman, Inc.

Bloom B. S. (Ed.) Englehart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives, handbook I: The cognitive domain.* New York: David McKay.

Glod, M. (Monday, June 1, 2009). "46 states, D.C. plan to draft common education standards." *Washington Post* [retrieved June 15, 2009] http://www.washingtonpost.com/wp-dyn/content/article/2009/05/31/AR2009053102339.html?referrer=emailarticle

Hattie, J. (October 2002). "What are the attributes of excellent teachers?" Presentation at the New Zealand Council for Educational Research Annual Conference, University of Auckland.

Hess, K. (2004). "Applying Webb's Depth-of-Knowledge (DOK) Levels in reading." [online] available: http://www.nciea.org/publications/DOKreading_KH08.pdf

Hess, K. (2005a). "Applying Webb's Depth-of-Knowledge (DOK) Levels in social studies." [online] available: http://www.nciea.org/publications/DOKsocialstudies_KH08.pdf

Hess, K. (2005b). "Applying Webb's Depth-of-Knowledge (DOK) Levels in writing." [online] available: http://www.nciea.org/publications/DOKwriting_KH08.pdf

Hess, K. (2006a). "Applying Webb's Depth-of-Knowledge (DOK) Levels in science." [online] available: http://www.nciea.org/publications/DOKscience_KH08.pdf

Hess, K. (2006b). "Exploring cognitive demand in instruction and assessment." [online] available: http://www.nciea.org/publications/DOK_ApplyingWebb_KH08.pdf

National Research Council. (2001). Pellegrino, J., Chudowsky, N., & Glaser, R. (Eds.) *Knowing what student know: The science and design of educational assessment*. Washington, D.C.: Academy Press.

Petit, M. & Hess, K. (2006). "Applying Webb's Depth-of-Knowledge (DOK) and NAEP levels of complexity in mathematics." [online] available: http://www.nciea.org/publications/DOKmath_KH08.pdf

The Standards Company LLC. (2008a). "Study of the alignment of student assignments to the academic standards in the state of Nevada pursuant to Senate Bill 184, Chap. 420, Statutes of Nevada 2007." Retrieved April 13, 2009, from Legislative Counsel Bureau, Nevada State Legislature, technical report, http://www.leg.state.nv.us/lcb/fiscal/Final_Report-Curriculum_Study.pdf .

The Standards Company LLC. (2008b). "Analysis of the enacted curriculum for the Oklahoma State Department of Education for the collection period February – March, 2008." Oklahoma State Department of Education, unpublished technical report.

Webb, N. (March 28, 2002) "Depth-of-Knowledge Levels for four content areas," unpublished paper.

Webb, N. (August 1999). Research Monograph No. 18: "Alignment of science and mathematics standards and assessments in four states." Washington, D.C.: CCSSO.

Webb, N. (1997). Research Monograph Number 6: "Criteria for alignment of expectations and assessments on mathematics and science education. Washington, D.C.: CCSSO.

