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Cognitive Rigor: Blending the Strengths of Bloom's Taxonomy and Webb's Depth of Knowledge to Enhance Classroom-level Processes

Karin K. Hess[1]

Ben S. Jones[2]

Dennis Carlock[3]

John R. Walkup[4]

Abstract

To teach the rigorous skills and knowledge students need to succeed in future college-entry courses and workforce training programs, education stakeholders have increasingly called for more rigorous curricula, instruction, and assessments. Identifying the critical attributes of rigor and measuring its appearance in curricular materials is therefore fundamental to progress in this area. By superposing two widely accepted models for describing rigor — Bloom's Taxonomy of Educational Objectives and Webb's Depth-of-Knowledge (DOK) model — this article defines cognitive rigor (CR) and introduces the CR matrix for analyzing instruction and enhancing teacher lesson planning. Two large-scale collections of student work samples analyzed using the CR matrix are presented, illustrating the preponderance of curricular items aligned to each cell in the matrix. Educators should use the cognitive rigor matrix to align the content in their curricular materials to the instructional techniques used in classroom delivery.

Key words: Bloom's Taxonomy, Webb's depth of knowledge, cognitive rigor, critical thinking, enacted curriculum, delivered curriculum

Introduction

A mainstay for over 50 years, Bloom's Taxonomy helps teachers formulate lessons that practice and develop thinking skills over a wide range of cognitive complexity. (Bloom, 1956) Although later revised by a team of education researchers headed by Anderson and Krathwohl (2001), the overall intent of the taxonomy remains: Categorize questions and activities according to their levels of abstraction. However, Bloom's Taxonomy suffers limitations when selecting test items and formulating questioning strategies because it uses verbs to differentiate taxonomy levels — many verbs appear at multiple levels and do not clearly articulate the intended complexity implied by the taxonomy. A new model of rigor, depth of knowledge (DOK), fills this void. The resulting combination of Bloom's Taxonomy and depth of knowledge — cognitive rigor — forms a comprehensive structure for defining rigor, thus posing a wide range of uses at all levels of curriculum development and delivery.

1 Karin K. Hess is a Senior Associate at the National Center for the Improvement of Educational Assessment. National Center for the Improvement of Educational Assessment, PO Box 351, Dover, NH 03821-0351 khess@nciea.org

2 Ben S. Jones is the Director of Research for The Standards Company LLC. The Standards Company LLC, 575 W. Alluvial Ave., Clovis, CA 93611 bjones@standardsco.com

3 Dennis Carlock is an independent curriculum analyst from Clovis, CA.

4 John R. Walkup is company president of The Standards Company LLC, Clovis. The Standards Company LLC, 575 W. Alluvial Ave., Clovis, CA 93611 jwalkup@standardsco.com

In one imaginary setting, a professional learning community of high school teachers prepares a common lesson plan centered on the causes of World War I. Their years of experience and professional development have developed considerable skill in associating differing levels of the revised Bloom's Taxonomy with their assignment questions. They know that e*xplaining* the meaning of a metaphor aligns to the *analyze* level and that if they need an *evaluate*-level question they can begin with the verb *critique*. So trawling up the (revised) taxonomy levels snares a string of questions that will enhance engagement and compel students to examine history a variety of angles.

> The lowest taxonomy level, *remember*, produces an obvious question: “List four causes of WWI.” Although this question will fail to activate higher-order thinking, everyone agrees that it will help at least compel students to pay attention to the lesson.
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> “Describe each cause in your own words” addresses the *understand* level of the taxonomy. Although the teachers disagree on whether the question truly constitutes high order, all agree that responding will intellectually challenge their students more than simply listing the causes.
>
> The *analyze* level delivers an enticing possibility: “How did each cause affect the other causes?” A similar challenge awaits students responding to the next offering aimed at the fifth (*evaluate*) level: “Rank the causes from most to least important and justify.”
>
> Not wanting to be outdone, another teacher offers her own contribution: “Suppose the first cause never took place; write an essay on what would have happened and why.” An argument over the answer breaks out among the teachers over this sixth-order (*create*) question, reminding them of the importance of Bloom's Taxonomy when developing a stimulating and engaging curriculum.

Beginning with Bloom

Although Bloom originally identified three separate domains of educational activities, most educators have trained their attention on the one associated with mental skill — the cognitive (knowledge) domain. Anderson and Krathwohl's revision of Bloom's Taxonomy (2001) presented a structure for rethinking this domain. (See Table 1.) Whereas the original cognitive domain possessed only one dimension, the revised version encompasses two: Cognitive processes *and* knowledge. The cognitive processes resemble those found in the original taxonomy, but the placement of each level on the taxonomy continuum shifted (e.g., *evaluation* no longer resides at the highest level) and includes expanded and clarified descriptions 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 content (characterized by factual, conceptual, procedural, and metacognitive knowledge) and thought processes.

> The teachers in the professional learning community look back on their meeting with satisfaction — each question they formulated addressed distinct thinking processes. Later, however, these teachers discover that Bloom's Taxonomy offers insufficient guidance in formulating assessment and instructional delivery strategies. With no natural tie between the taxonomy levels and the depth of understanding required to respond to each question, their assessment strategies begin to fall back on traditional crude rules of thumb and gut feel. As one teachers puts it, “Not all of the questions residing at the same level of Bloom's Taxonomy offer my students the same mental challenge.” Complicating matters even further, many verbs such as *compare* and *explain* appear at multiple levels in the taxonomy.

Later, some of the teachers begin to discover a new measure of rigor in the literature that bridges this deficiency: *Depth of knowledge*.

Table 1
Comparison of descriptors associated with the cognitive process dimensions of Bloom's original taxonomy (1956) and the revised Bloom's Taxonomy of Anderson and Krathwohl (2001).

Bloom's Taxonomy (1956)	**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, provide examples, classify, categorize, summarize, generalize, infer a logical conclusion (such as from examples given), predict, match similar ideas, explain, compare/contrast, 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 and 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* Judge 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* Combine elements to form a coherent whole, reorganize elements into new patterns/structures, generate, hypothesize, design, plan, construct, produce for a specific purpose

Webb's DOK model

Depth of knowledge (DOK) forms another important perspective of cognitive complexity. The best-known work in this area, that of Norman Webb (1997, 1999), compelled states to rethink the meaning of test alignment to include both the content assessed in a test item and the depth to which we expect students to demonstrate understanding of that content. In other words, the complexity of both the content (e.g., interpreting literal versus figurative language) and the required task (e.g., solving routine versus non-routine problems) both define each DOK level shown in Table 2.

Table 2
Webb's depth-of-knowledge (DOK) levels (Webb 1997, 1999)

Level	Description
DOK-1	Recall & Reproduction — Recall a fact, term, principle, or concept; perform a routine procedure.
DOK-2	Basic Application of Skills/Concepts — Use information, conceptual knowledge; select appropriate procedures for a task; perform two or more steps with decision points along the way; solve routine problems; organize or display data; interpret or use simple graphs.
DOK-3	Strategic Thinking — Reason or develop a plan to approach a problem; employ some decision-making and justification; solve abstract, complex, or non-routine problems, complex. (DOK-3 problems often allow more than one possible answer.)
DOK-4	Extended Thinking — Perform investigations or apply concepts and skills to the real world that require time to research, problem solve, and process multiple conditions of the problem or task; perform non-routine manipulations across disciplines, content areas, or multiple sources.

Although related through their natural ties to the complexity of thought, Bloom's Taxonomy and Webb's DOK model differ in scope and application. Bloom's Taxonomy categorizes the cognitive skills required of the brain when faced with a new task, therefore describing the type of thinking processes necessary to answer a question. The DOK model, 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).

Today, interpreting and assigning intended DOK levels to both the standards and the related assessment items form critical components of any alignment analysis. Educators have applied Webb's DOK levels across all content areas (Hess, 2004, 2005a, 2005b, 2006a, 2006b; Petit & Hess, 2006). Many states and districts employ DOK to designate the depth and complexity of state standards 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 curriculum and classroom assessments for a greater range of cognitive demand.

> Teachers in the professional learning community slowly begin to assimilate depth of knowledge in their lesson planning, as they find identifying the DOK levels of questions an effective step in formulating questioning strategies and optimizing assessments. One teacher notes that DOK levels do not correlate to her notion of "difficulty." Another agrees, pointing out that students will struggle more to remember all four causes than only one, but both activities reside at the DOK-1 level.
>
> The teachers soon begin to see how depth of knowledge fits in lesson planning. "A DOK-3 or DOK-4 learning activity requires a great deal of assimilation of information. My students will need to converse at length in groups to reinforce what they learned earlier and will need more wait time and engagement with the content." Another teacher chimes in: "I can see how categorizing my questions according to depth of knowledge helps in creating assessments. Too many DOK-1 questions and I'm not sure I have truly measured their conceptual understanding

of the content." The teachers conclude that a reasonable blend of DOK-1, DOK-2, and DOK-3 questions comprises a reasonable assessment, relegating DOK-4 questions to in-class projects. They also agree to apply DOK-3 and DOK-4 activities toward content they expect their students to know more deeply.

As these teachers discovered, identifying the DOK levels of questions in tests and class assignments helps articulate how deeply students must understand the related content to complete necessary tasks. As examples, students need a greater depth of understanding 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).

Cognitive rigor and the CR matrix

Because no simple one-to-one correspondence relates Bloom's Taxonomy and depth of knowledge, Hess (2006b) superposed them. The resulting cognitive rigor (CR) matrix in Table 3 vividly connects, yet clearly distinguishes, the two schemata, allowing educators to examine the rigor associated with tasks that might seem at first glance comparable in complexity. (See appendix.) The cognitive rigor matrix soon found use in states just beginning to appreciate the role cognitive complexity played in test design and item development (Hess, 2006a, 2006b).

Although extending a pattern in mathematics may not look anything like distinguishing fact from opinion in English language arts, the two tasks reside in the same cell of the CR matrix and therefore share many common features: Both evoke similar thought processes and require similar instructional and assessment strategies. For curriculum analysis purposes, the CR matrix effectively categorizes such 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," resides within the [DOK-1, Bloom-3] cell of the CR matrix. Using the CR matrix to plot the cognitive rigor of mathematics assignments, as shown in Fig. 1, a researcher or practitioner can discover the extent to which the curriculum targets this level of cognitive rigor compared to the [3, 2] cell, which similarly requires application of learned concepts to new situations (Bloom-3) but requires some decision-making to perform (DOK-2).

Research results applying the CR matrix

In two large-scale studies of the enacted (i.e., taught) mathematics and English language arts curricula, teachers from 200 Nevada and Oklahoma public schools submitted for analysis over 200,000 samples of student work, which included homework samples, tests, quizzes, and worksheets. (The Standards Company LLC, 2008a, 2008b). Curriculum specialists analyzed each item on each work sample and, using the CR matrix, assigned to each collected sample its overall DOK level and the highest Bloom's Taxonomy level appearing on the sample. The CR density plots in Figure 1 illustrate results from the two studies, displaying the percentage of assignments as a color shade. (The studies encompass hundreds of such plots disaggregated according to grade level, subject area/ course, socioeconomic status, and so on; the two plots shown in Figure 1 merely represent cumulative examples for each subject area.)

Results for English language arts indicate a preponderance of assignments correlating to the [2, 2] cell of cognitive rigor. (The two coordinates denote the levels of DOK and Bloom's Taxonomy, respectively.) Mathematics assignments, on the other hand, heavily sampled the [1, 1] and [1, 3] cells. Although assignments associated with the latter, such as solving algebraic equations and non-rote arithmetic, help students practice crucial numeracy and fluency skills in mathematics, the result nonetheless may point to an over-reliance on teaching straightforward applications of routine steps.

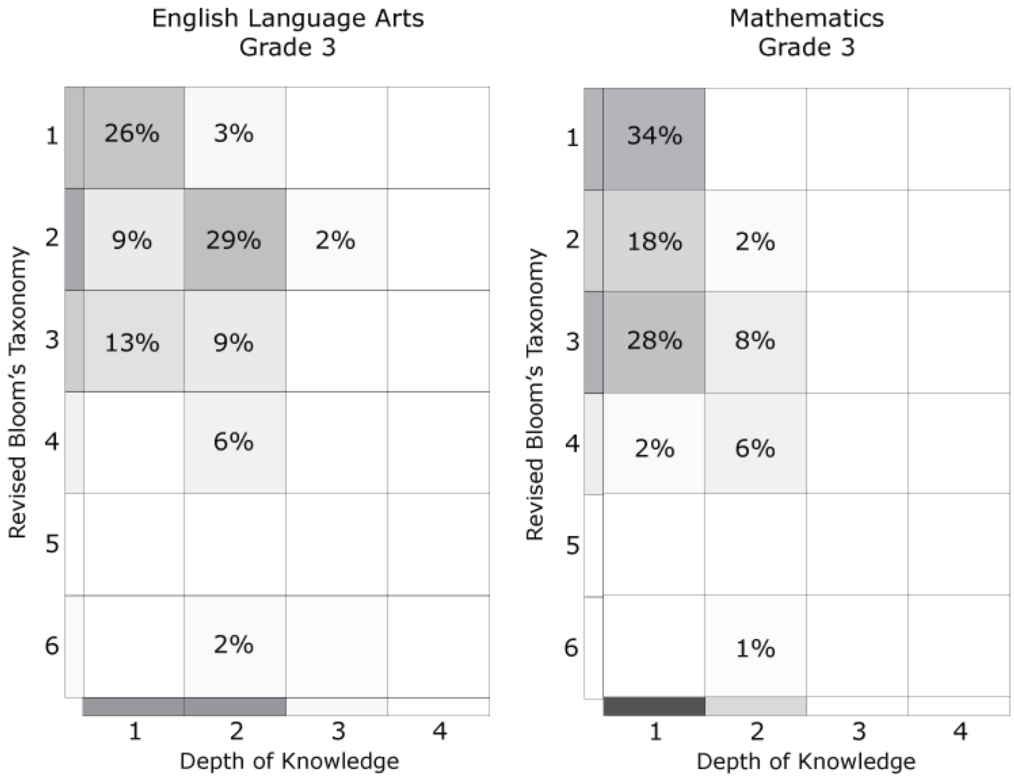

Figure 1: Density plots comparing the cognitive rigor of student work assignments collected from 205 schools across two states. (The Standards Company LLC 2008a, The Standards Company LLC 2008b). Although the study encompassed all public school grade levels, the above plots only show third-grade results. Thin cells lined along the left and bottom display cumulative percentages for each row or column. The English language arts data comprises 12,060 samples of student work; mathematics comprises 8,428. Results that round to 0 remain unlabeled for clarity; as a result, percentages might not always sum to 100%.

Figure 1 also indicates that the Bloom's Taxonomy levels reached by both subject areas appeared similar, but mathematics sampled the lowest (DOK-1) levels of depth of knowledge to a greater extent, indicating that the mathematics curriculum delivered by teachers may rely on a shallower understanding of the subject than English language arts.

Discussion

Students learn skills and acquire knowledge more readily when they can transfer their learning to new or more complex situations, a process more likely to occur once they have developed a deep understanding of content (National Research Council, 2001). Therefore, ensuring that a curriculum aligns to standards *alone* will not prepare students for the challenges of the twenty-first century. Teachers must therefore provide *all* students with challenging tasks and demanding goals, structure learning so that students can reach high goals, and enhance both surface and deep learning of content (Hattie, 2002).

Both Bloom's Taxonomy and Webb's depth of knowledge therefore serve important functions in education reform at the state level in terms of standards development and assessment alignment. 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 can enhance instructional and assessment practices at the classroom level as well. Superposing the two cognitive complexity measures produces a means of analyzing the emphasis placed on each intersection of the matrix. As educators become more skilled at recognizing cognitive rigor and analyzing its implications for instruction and assessment, they can enhance learning opportunities for all students and across all subject areas and grade levels. Because students need exposure to novel and complex activities every day, schools in the twenty-first century should prepare students by providing them with a curriculum that spans a wide range of the cognitive rigor matrix.

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Appendix

Table 3
Cognitive rigor (CR) matrix with curricular examples.

Revised Bloom's Taxonomy levels	Webb's Depth-of-Knowledge Levels Level 1 Recall and Reproduction	Level 2 Skills and Concepts	Level 3 Strategic Thinking/ Reasoning	Level 4 Extended Thinking
Remember Retrieve knowledge from long-term memory, recognize, recall, locate, identify	Recall, recognize, locate basic facts, ideas, principles Recall or identify conversions: between 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, predict, compare/contrast, match like ideas, explain, construct models	Compose/decompose numbers Evaluate an expression Locate points on a grid Symbolize math relationships Write simple sentences Describe/explain how or why	Specify and explain relationships Give non-examples/examples Make and record observations Summarize results, concepts, ideas Infer or predict from data or texts Identify main ideas	Explain, generalize, or connect ideas using supporting evidence 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 procedures Solve a one-step problem Calculate, measure, apply a rule Apply an algorithm or formula Represent in words or diagrams a concept or relationship Apply rules or use resources to edit spelling and grammar	Select a procedure according to task needed and perform it Solve routine problem applying multiple concepts or decision points Retrieve information from a graph and use it solve a multi-step problem Use models to represent concepts Write paragraph using appropriate organization, text structure	Use concepts to solve non-routine problems Design investigation for a specific purpose or research question Conduct a designed investigation 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 Extend a pattern Identify use of literary devices Identify text structure of paragraph	Compare information within or across data sets or texts Analyze and draw conclusions Generalize a pattern Organize/interpret data Analyze author's craft or viewpoint	Analyze multiple sources of evidence or multiple works by the same author, or across genres 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, and evaluate relevancy and accuracy Draw and 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 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 situations