How Do You Recognize a Rigorous and Relevant Curriculum? : A Method for Analyzing Rigor and Relevance in Science and Mathematics Curricula

The Situation

Selecting and implementing rigorous and relevant curricula is paramount to success in today's educational climate. Since the publication of a *Nation at Risk* (1983), schools across the U.S. have sought to meet a growing demand from business and government to increase the level of academic rigor for all students*.* Our nation continues to lag behind others in terms of the rigor of our science and mathematics. This situation continues to place strains on US business and industry to meet growing employment need for science, technology, engineering and mathematics (STEM) careers. Additionally, educational research consistently demonstrates that efforts to make learning relevant through application of knowledge in real-world contexts improves knowledge retention and transfer and enhances students' motivation to learn (Lave & Wenger, 1991). Today, accountability legislation, such as *No Child Left Behind* (2001) creates pressure for educators throughout our educational system to take a serious look at the level of rigor and relevance in curricula, especially in the areas of mathematics and science, selected to support local, district, state and national learning priorities.

A Problem to Solve

Despite the pressure to identify and select rigorous and relevant curricula, there is no clear and consistent way to describe or "label" the rigor and relevance of a particular curriculum. When selecting curricula to meet educational priorities, how do educators distinguish rigorous and relevant curricula from curricula that are neither rigorous nor relevant? Other stakeholders in the educational system have "reports" to guide decisions; consider the following examples:

- Students and parents have the guidance of the standard report card to help identify learning progress and areas for improvement.
- Parents and taxpayers often have the guidance of a "school report card" when evaluating school options in the local area.
- Legislators and constituents have the measure of Annual Yearly Progress (AYP) to guide them in determining funding for school districts.

What "product label" or "report card" guides an educator or administrator as he or she searches for new materials and curricula that meet educational priorities in a rigorous and relevant way? We contend that measuring and reporting the relative level of rigor and relevance of content in curricula may provide useful criteria by which educators and administrators may sort among the options in today's instructional materials market.

A Solution

The purpose of this paper is to introduce and demonstrate a method for analyzing and reporting the rigor and relevance of mathematics and science content found in curricula. By no means do we suggest that the method, or its results, constitute a comprehensive "report card" by which a stakeholder may evaluate a curriculum.

Instead, we suggest that the method discussed here is a starting point for producing a consistent way to describe the level of rigor and relevance for content across a set of curricula. Doing so allows educators and administrators to make comparisons between the rigor and relevance of the same content in other curricula. We maintain that such examination will not only inform and improve instructional materials and assessments we produce for our programs, but will inform the process by which those artifacts are provided to instructors and students alike. Furthermore, we believe employing the method described creates an opportunity to encourage accountability for rigor and relevance in products produced by those individuals in the educational industry who develop and distribute ready-to-use curricula. In the paper, we will outline the context from which the method is derived and demonstrate how the method was applied to analyze the level of rigor and relevance for mathematics and science content in one of the foundation courses for the Project Lead The Way® Pathway to Engineering™ curricula.

The Method

This section outlines the method introduced in the opening paragraphs. The method described here draws upon the work of two ongoing conversations in education – curricula analysis (Porter, 2004; Webb, 1997) and the relationship between rigor, relevance, and academic achievement (Daggett, 2005). First, in an effort to contextualize the method, we outline relevant definitions and assumptions from both discussions. Second, we describe guiding principles for the design of a method to analyze and report the rigor and relevance of mathematics and science content in the selected Project Lead The Way® curriculum.

Curricula Analysis

An important objective for the method introduced in these pages comes from an ongoing discussion about curricula analysis. In *Complementary Methods for Research in Education*, Andrew Porter (2004) defines curricula analysis as the systematic process of isolating and analyzing targeted features of a curriculum. Curricula analysis most commonly involves describing and isolating a particular set of content (e. g., mathematics content, science content, or language arts content) in a curriculum and then analyzing the performance expectations, or cognitive demand, that describe what students are to know and do with the content. Content, is defined as the domain specific declarative, procedural, tactile and situative knowledge targeted by a curriculum. Performance expectations are generally defined as the level at which a student is expected to know and employ the content as a result of the instructional activities and assessments conducted in the curriculum. Through systematic analysis of curricula, educators can begin to compare and contrast various aspects across multiple curricula.

Porter (2002, 2004) also makes distinctions regarding the four levels at which curricula analysis may occur. The four levels at which one may analyze a curriculum include intended, enacted, assessed, and learned. Table 1 reflects the focus of curricula analysis at each of the four levels.

Table 1. Primary Focus of Curricula Analysis at Each Dimension of a Curriculum

Level	**Primary Focus of Curricula Analysis**
Intended Curriculum	Analysis is concerned with examining the content (e.g., declarative, procedural, tactile, and situative knowledge) and the performance expectations, which is the level at which a

	student is expected to know and use the content as it is communicated in the documents and materials created to guide instruction and assessment.
Enacted Curriculum	Analysis is concerned with examining the content and the performance expectations as it is enacted by the instructor in the classroom and in the learning contexts.
Assessed Curriculum	Analysis is concerned with examining the content and performance expectations represented by the tasks, questions, and performance tasks contained in assessment materials.
Learned Curriculum	Analysis is concerned with measuring the content and level at which learners enact the performance expectations in a targeted context.

The method introduced in this paper is only concerned with examining the intended curriculum. Specifically, we are interested in the content and performance expectations as they are communicated in the documents and materials created to guide instruction and assessment. This is not to suggest that conducting similar analyses at the other levels of the curriculum is not important. Applying Porter's (2004) methods to analyze the similarities and differences among the various levels would certainly be a worthy endeavor, however it is beyond the scope of the method introduced and demonstrated in this paper.

Rigor and Relevance

Porter’s (2002, 2004) work provides one of the big picture objectives for the method discussed in this paper. A second objective for the method described in this paper comes from Willard Daggett’s (2005) work on the relationship between academic achievement, rigor and relevance. Daggett (2005) suggests that lasting gains in student achievement come from applying high-rigor expectations for the content in relevant, real-world settings. Here, rigor is defined as the level of cognitive demand, or the quantity and quality of the cognitive processes, required to complete an instructional or assessment task. Relevance, on the other hand, is defined as the degree to which the context in which the content is to be applied, or transferred, approximates the real-world. Daggett (2005) suggests that painting a complete picture of the performance expectations for any content area requires consideration of both cognitive rigor and relevance.

Guiding Principles for the Method

As stated in the introduction, our goal was to design a method that provides a consistent “report card” regarding the rigor and relevance of mathematics and science content represented in the Project Lead The Way Curricula. The method employed to achieve this goal is based upon principles for analyzing curricula as outlined by both Porter and Daggett. From Porter, we conclude that a method for analyzing the intended curriculum across multiple courses must include two processes. One for systematically identifying and isolating selected content and a second process for analyzing the performance expectations for the content. From Daggett, we conclude that an informative method for reporting on the performance expectations for content in a curriculum will involve a measure that considers both cognitive rigor and relevance.

Taken together, these two conclusions form guiding principles for the method demonstrated in the next section.

Demonstrating the Method

We designed and demonstrated our method for analyzing and reporting on the rigor and relevance of science and mathematics content by examining one of the foundation courses Project Lead the Way® *Introduction to Engineering Design*™. To conduct the initial analysis we used the performance and assessment objectives, as stated in the course lesson plans, as proxies for the science and mathematics content and statements of expectation regarding student performance throughout the course. In Project Lead The Way® curricula the performance objectives are statements of expectation regarding what students are to know and be able to do following completion of each lesson. The performance objectives are based upon a set of overarching concepts for each course. These concepts represent what students are to understand at the end of the course and are translated into a set of performance objectives, which then guide development of the instructional activities, projects, and problems used to teach the concepts. In order to understand fully the content described in the performance objectives, it was necessary to examine thoroughly the course concepts as the two artifacts share an integral linkage in the course design. Likewise, to understand the performance expectations expressed in the performance objectives it was necessary to examine closely the course activities, projects, and problems as these artifacts also share an integral linkage. The assessment objectives are statements of expectation regarding how students are to demonstrate their understanding of the course concepts. In the lesson, the statements are written in the form of behavioral objectives and represent both course content and performance expectations. The statements are located under a section called "Assessment" in the Project Lead the Way® curricula. The assessment objectives are organized by Wiggins and McTighe's (2005) six facets of understanding and are provided as an expectation for students to demonstrate real-world application and critical thinking with regard to the course concepts as students complete each lesson. A total of 168 performance and assessment objectives were included in the analysis described. Throughout the method described here, the performance and assessment objectives are generically referred to as course objectives.

Step one – Defining a framework for measuring performance expectations.

Our team made it a priority to identify a framework for performance expectations that accounted for both cognitive demand (rigor) and the context for applying the content (relevance). We turned to Webb's (1997, 2002) Depth of Knowledge (DOK) model as the base framework because the existing definitions for each level in the model encompass both cognitive rigor and context for application. It should be noted that the term knowledge, as it is used here, is intended to encompass all forms of knowledge (e. g., procedural, declarative, tactile, or situative). The following table reflects our adapted version of the model. In the model, as the levels increase so does the cognitive demand (rigor) and proximity to real-world application (relevance). Thus, an objective, instructional task and assessment item assigned to level one will have the lowest cognitive demands and will likely reflect application to tasks in the domain. Whereas, an item assigned to level four will have the highest cognitive demands and will likely reflect application in real-world unpredictable contexts.

DOK Level	Title of Level
1	Recall and Reproduction
2	Skills and Concepts
3	Short-term Strategic Thinking
4	Extended Strategic Thinking

Webb's (2002) definitions of the Depth of Knowledge Levels for Science, Mathematics and Language Arts served as a base definition for each level in this analysis. Input from experts in the field of engineering was used to refine the model and definition terminology. This adaptation is intended to ensure that the terms used speak to both professionals in real-world engineering practice and educators alike. A detailed description of performance expectations at each level is located in Appendix A.

As this particular model was applied to assign a DOK Level to each course objective, the following served as general guidelines for the evaluators:

- The DOK Level assigned should reflect the level of work students are most commonly required to perform in order for the response to be deemed acceptable.
- The DOK Level should reflect the complexity of the cognitive processes demanded by the task outlined by the objective, rather than its difficulty. Ultimately the DOK Level describes the kind of thinking required by a task, not whether or not the task is "difficult".

- If there is a question regarding which of two levels a statement addresses, such as Level 1 or Level 2, or Level 2 or Level 3, it is appropriate to select the higher of the two levels.
- The DOK Level should be assigned based upon the cognitive demands required by the central performance described in the objective.
- The objective's central verb(s) alone is not sufficient information to assign a DOK Level. Evaluators must also consider the complexity of the task and information, conventional levels of prior knowledge for students at the grade level, and the mental processes used to satisfy the requirements set forth in the objective.

Step two – Applying the framework to analyze the rigor and relevance of all existing course objectives.

A reviewer familiar with using the DOK Levels began the analysis by assigning a Depth-of-Knowledge Level to each objective in the Introduction to Engineering Design™ (IED) course, which is one of three-foundation course in the PLTW® Pathway to Engineering™ program. The reviewer worked chronologically through the curriculum starting with the first unit and continued working through each lesson in order. Performance objectives for the lesson were evaluated first followed by a review of the lesson's assessment objectives. The level assigned represented the highest level of cognitive processing demanded for a student to satisfactorily demonstrate attainment of the objective. To understand the level of expectation for "satisfactory attainment" the reviewer used the IED course materials to investigate the nature of the content, the instructional treatments used, and the assessment rubrics related to each objective. Once the supporting information was reviewed, a level was assigned. Periodically, the evaluator reviewed previously evaluated objectives to ensure consistent application of the four levels among objectives with a similar focus. If a discrepancy occurred the reviewer re-evaluated the information available for both objectives and made a final assignment.

A sample of 33 randomly selected course objectives out of the total 168 (containing both performance and assessment objectives) were independently analyzed by a second trained evaluator. The sample of objectives was selected using a simple randomization technique. The second evaluator assigned a DOK Level, one through four, to each of the 33 objectives in the sample using the same descriptions and procedures described earlier. An attribute agreement analysis was conducted using Mini-Tab® to evaluate the level of concurrence between the two evaluator's DOK assignments. Out of 33 statements inspected 28, or 84.85%, of the assigned levels provided by both evaluators matched. To evaluate the level of agreement Cohen's kappa (κ) and Kendall's coefficient of concordance (W) were both employed.

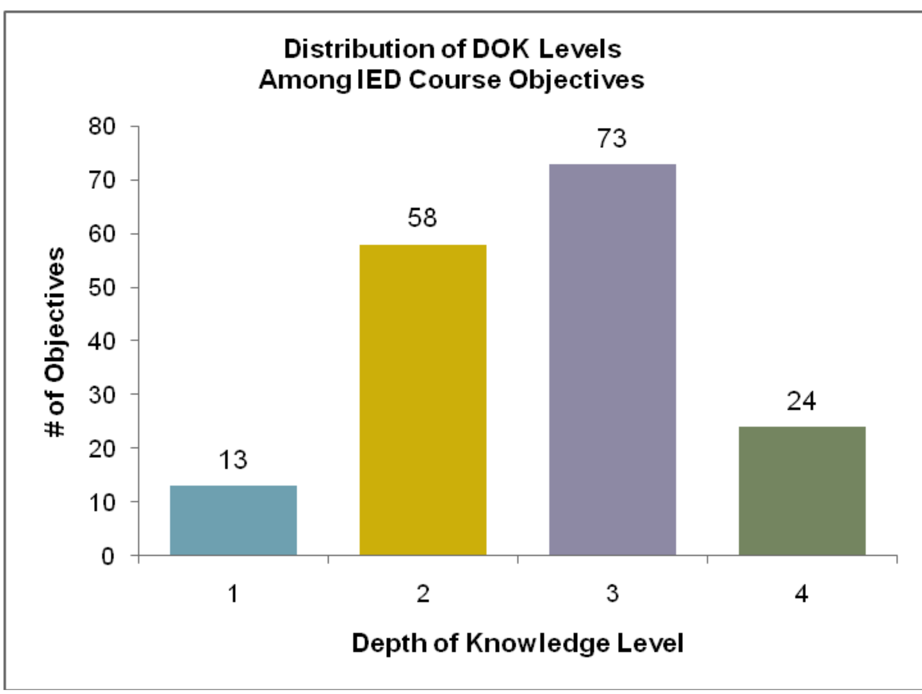
Cohen's kappa (κ) statistic measures absolute agreement between two raters who each classify a set number of items into a set of mutually exclusive categories (Cohen, 1960). This statistic is considered more robust than calculating only a simple percent agreement as it takes chance agreement into account. The analysis reports a value between 0 and 1. κ values closer to one indicate stronger agreement between the raters involved. Landis & Koch (1977) indicate the following rule-of-thumb for evaluating Cohen's kappa measures: κ = 0.41 to 0.60 reflects moderate inter-rater agreement, κ=0.61 to 0.80 substantial, and κ=0.81-1.00 almost perfect. Following analysis of the ratings the level of agreement between the two raters on the 33 items was found to be substantial κ=0.75983 (P <0.000). This represents a level of agreement significantly different (α=.05) from those that would be achieved by chance.

Kendall's coefficient of concordance (W) is another statistic often used in combination with Cohen’s kappa to evaluate the degree of concordance or discordance between independent raters (Siegel & Castellan, 1988). As a comparison, Cohen’s kappa coefficient reflects the absolute agreement among multiple raters. κ doesn't take into account the order of the scores or the severity of misclassifications among raters (i.e. one rater assigns the objective to Level 1 while the other assigns the objective to Level 4). The coefficient of concordance statistic is, however, sensitive to ordering and to the seriousness of misclassifications among raters. Kendall's coefficient of concordance can range from 0 to 1; the higher the value of Kendall's, the stronger the association. After data analysis W= 0.911609 (df=32, $\chi 2$=58.3430, P<0.0030). This indicated an acceptable level of concordance between the two rater’s assignment of DOK Levels that is significantly different (α=.05) from those achieved by chance alone.

While attribute agreement analysis provided evidence to suggest that the first evaluator’s original assignments were acceptable, a review of data output from the Cohen’s κ analysis was used to reveal areas where absolute agreement differed most. Based upon this analysis it was determined that the evaluators most consistently matched on assigning Level 4 (κ=1, P<0.000). The source of disagreement between the evaluators was mostly found with assignment of Levels 2 & 3 (κ=0.67836 and κ=0.69274, P=0.000 respectively). To address this issue, the primary investigator reviewed those objectives originally assigned a Level two and three to determine if any changes were merited based upon feedback from the second evaluator. Only a few adjustments were made to the originally assigned levels based upon this second review. Appendix B contains a sample of the objectives showing the DOK Level to which they were assigned.

Based upon this process 7.74% of the course objectives were assigned to Level 1 – Recall and Reproduction; 34.52% were assigned to Level 2 – Working with Skills and Concepts; 43.45% were assigned to Level 3 – Short Term Strategic Thinking and 14.29% were assigned to Level 4 – Extended Strategic Thinking. Chart 1 shows the distribution of all course objectives among the four Levels in the DOK model. As stated earlier, the DOK Levels defined were such that higher DOK Levels (Levels 3 and 4) reflect performance and assessment objectives that have a higher degree of rigor (cognitive demand) and relevance (proximity to real-world application). In this case, 57.73% of the performance and assessment objectives demonstrated a high degree of cognitive rigor and a closer proximity to real-world application.

Chart 1. Analysis of Rigor and Relevance in All Course Objectives



DOK Level	*Frequency*
1	13
2	58
3	73
4	24

Count	168
Mean	2.59
Mode	3
*SD**	0.815
Median	3.00

*SD=Standard Deviation

Step three – Identifying mathematics and science content for further analysis.

Next, all 168 course objectives were reviewed to identify those objectives that most emphasized mathematics and science concepts and skills. Nationally recognized standard frameworks for both mathematics and science were used to guide the categorization process. Nationally recognized standards for mathematics and science were used to define parameters for identifying course objectives with an emphasis in either or both content areas. Mathematics concepts are defined by *Principles and Standards for School Mathematics* as published by the National Council of Teachers of Mathematics (NCTM). Science concepts are defined by *National Science Education Standards* as published by the National Research Council (NRC).

A reviewer familiar with the IED course objectives initially reviewed each objective to identify objectives emphasizing mathematics or science. *Principles and Standards for School Mathematics* as defined by NCTM served as a guide for recognizing mathematic subject matter. *National Science Education Standards* as defined by NRC served as a guide for recognizing science subject matter content. “Emphasis on mathematics or science,” for this analysis was defined as active employment or use of the mathematics or science skill and knowledge to meet some established expectation. Thus, both the subject matter and the expectation established for employing that subject matter were considered as each objective was analyzed.

To begin, each objective was reviewed with an eye toward the subject matter outlined in both sets of standards. Objectives were assigned to one of three categories: direct match, possible match, and no match. Direct matches between concepts addressed in the objectives and standards were flagged for inclusion in the DOK analysis. Objectives that did not have exact key word matches, but shared a relationship to concepts in either set of standards were flagged for further analysis. Objectives that emphasized neither mathematics nor science concepts were omitted for this analysis.

Next, the reviewer used the IED course materials and both sets of standards to investigate each of those objectives flagged as potential matches in the initial pass. If the subject matter did in fact emphasize either science or mathematics content then that objective was also assigned to be included in the DOK analysis. Before finalizing the objectives to include in the analysis, a sample of objectives were shared with a reviewer familiar with both sets of standards to ensure valid identification of mathematics and science concepts. Appendix C shows example objectives included in this analysis and the standards to which they were linked. It is important to note that due to the nature of the objectives in the engineering context many of the objectives were identified to emphasize both science and mathematics concepts.

Out of 168 objectives in the IED course 88.69% (149) of the 168 total objectives in the IED course were identified to emphasize either, or both, mathematics and science content standards. 108 (64.28%) were identified for emphasizing one or more of the mathematics standards established by NCTM. 114 (67.85%) objectives were identified for emphasizing one or more of the stated science standards established by the NRC. Additionally, 47.65% (71) of the 168 course objectives included in this analysis demonstrated a dual emphasis on mathematics and science concepts.

Step four – Analyzing the relative level of rigor and relevance for mathematics and science content.

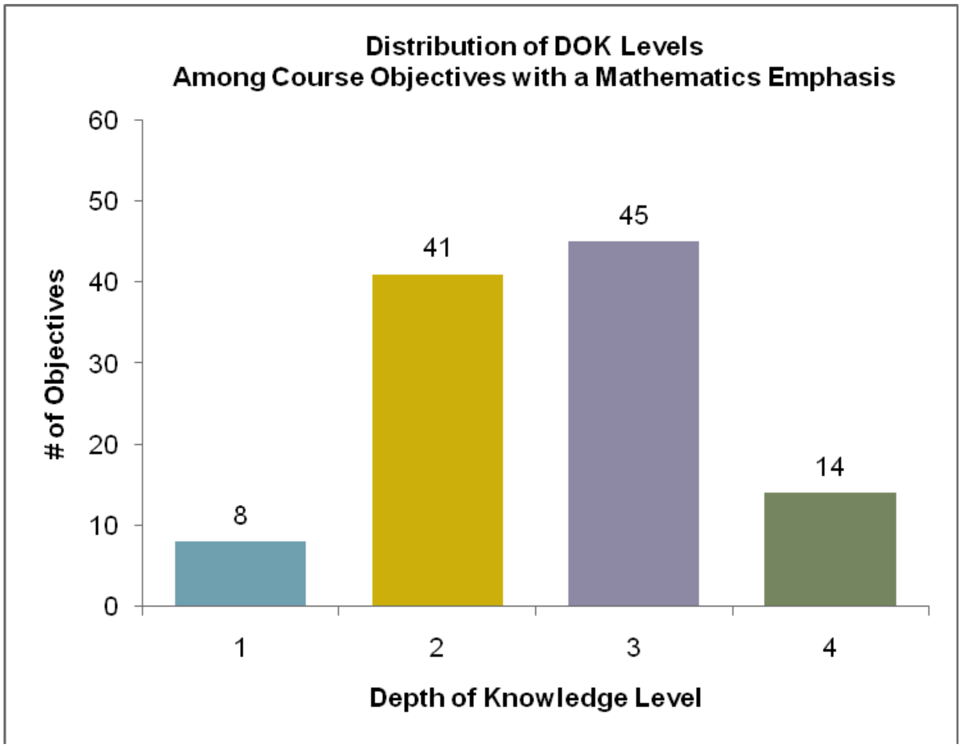
Once the objectives emphasizing mathematics and science content were isolated, the final step was to analyze the DOK Level to which each of those objectives were assigned. Given the original goal for this investigation, we chose descriptive statistics as the primary vehicle to analyze the data. First, we created a series of histograms to show how often the four DOK Levels occurred throughout course objectives with a mathematics emphasis. Second, we created a series of histograms to show how often the four DOK Levels occurred throughout course objectives with a science emphasis. In addition to the histograms, we also generated other measures of central tendency such as mean, median, mode and standard deviation.

Looking across the entire course, generally objectives that emphasize mathematics and science established an expectation for the use of short-term strategic thinking (DOK Level 3).

- 42.98% of objectives emphasizing science were assigned to DOK Level 3
- 41.67% of objectives emphasizing mathematics were assigned to DOK Level 3

Charts 2 and 3 demonstrate the distribution of course objectives by DOK Levels. As discussed before, the higher the DOK Level the higher the expectations for rigor and relevant application.

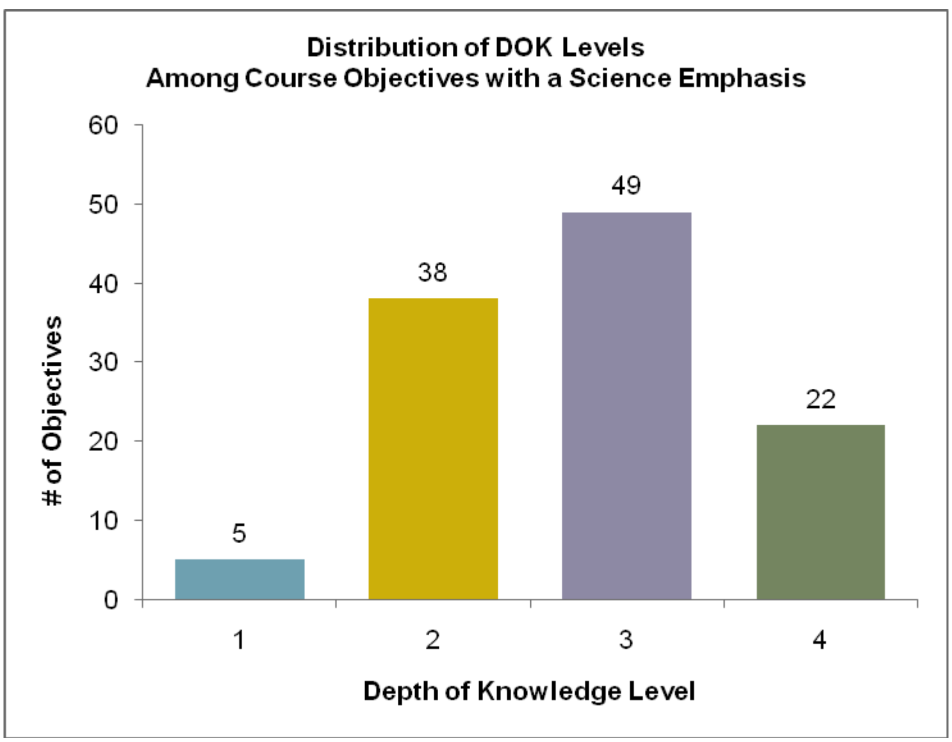
Chart 2. All Course Objectives Emphasizing Mathematics



DOK Level	*Frequency*
1	8
2	41
3	45
4	14

Mean	2.60
Mode	3
Median	3
SD	0.808
Count	108

Chart 3. All Course Objectives Emphaizing Science



DOK Level	*Frequency*
1	5
2	38
3	49
4	22

Mean	2.77
Mode	3
Median	3
SD	0.810
Count	114

Results and Discussion

As stated in the introduction, our immediate purpose for identifying the method described here was to demonstrate a way to produce data by which educators and administrators can evaluate and understand the relative level or rigor and relevance in mathematics and science content in a curriculum. The method demonstrated affords educators and administrators' data that shows how extensively mathematics and science content is expressed in a curriculum. For example, the results demonstrate that a large proportion (88.69%) of the 168 course objectives emphasize mathematics and science content.

In addition, the method produces data that affords a closer look at the rigor and relevance of the mathematics and science content. Table 2 demonstrates how a detailed look at the data can be used to communicate additional information regarding the relative level of rigor and relevance. Table 3 demonstrates how the data may also be broken out by units of instruction within the course to provide another view of the rigor and relevance of mathematics and science content throughout the course.

Table 2. Detailed Analysis of Course Objectives by DOK Level

	Level 1	**Level 2**	**Level 3**	**Level 4**
	Increasing rigor → Increasing relevance →			
Performance Objectives				
Emphasizing Mathematics	11.76%	44.12%	36.77%	7.35%
Emphasizing Science	8.2%	44.26%	36.06%	11.48%
Assessment Objectives				
Emphasizing Mathematics	0	27.5%	50%	22.5%
Emphasizing Science	0	20.75%	50.95%	28.30%

From the data in Table 2, one can show that performance objectives for both mathematics and science place strong emphasis on working with skills and concepts, Level 2, and short-term strategic thinking, Level 3. On the other hand, assessment objectives tended to place a stronger emphasis on integration of skills and concepts through short-term strategic thinking – DOK Level 3, and extended strategic thinking - DOK Level 4. This is likely a reflection of the course design. As students initially learn and apply concepts through the instructional focus (performance objectives) prior to being expected to employ those same skills and knowledge to solve both projects and problems as part of assessment in the course.

Table 3. Analysis of Science and Mathematics Content by Course Unit

	Level 1	Level 2	Level 3	Level 4
Science Content	Increasing rigor → Increasing relevance →			
Unit 1 Objectives (n=32)	6.25%	34.37%	46.88%	12.5%
Unit 2 Objectives (n=34)	0	35.29%	41.18%	23.53%
Unit 3 Objectives (n=35)	8.57%	34.28%	42.86%	14.29%
Unit 4 Objectives (n=13)	0	23.08%	38.46%	38.46%
Mathematics Content				
Unit 1 Objectives (n=39)	5.13%	43.59%	41.02%	10.26%
Unit 2 Objectives (n=47)	8.51%	29.79%	48.93%	12.77%
Unit 3 Objectives (n=18)	11.11%	55.56%	27.78%	5.55%
Unit 4 Objectives (n=4)	0	0	25%	75%

From the data in Table 3, one can show the trends for objectives emphasizing both mathematics and science across all four units of the Introduction to Engineering Design™ course. Generally, the objectives emphasizing both mathematics and science in Units 1 thru 3 spanned all four Depth of Knowledge levels, but tended to concentrate on level 2, working with skills and concepts, and level 3, short-term strategic thinking. In contrast, objectives with a mathematics and science emphasis in Unit 4 had a higher concentration of objectives at level 3 (short-term strategic thinking) and level 4 (extended strategic thinking). This also seems to be a reflection of the course design. The last unit of the course appears to employ higher-level application of all skills and concepts learned in the course in the context of solving a real-world problem where the outcomes are not predictable.

As stated in the introduction, we be believe that using this method analyze curricula creates a win-win situation. Educators and administrators win because they have access to data so that they may make informed decisions about the rigor and relevance of content in curricula they plan to implement. Those involved in curricula development are able to obtain data that is useful in checking prior assumptions and making improvements to the rigor and relevance of the courses they develop. Providing a consistent language and method for evaluating curricula also affords the opportunity to begin making comparisons among curricula.

Current Projects and Future Directions

Project Lead The Way, Inc. is currently investing resources to conduct this same analysis on the remaining two courses in the foundation sequence – Principles of Engineering™ and Digital Electronics™. Once analysis is complete on these two courses data will be available to compare and contrast the three foundation courses using a consistent set of criteria. Data generated from the analysis of course materials being revised has proved valuable in making adjustments to the course content and performance expectations while the product is still in the field-testing phase of revision. As Principles of Engineering™ and Digital Electronics™ were analyzed, data was collected regarding the relative level of rigor and relevance found in the course activities, projects, and problems. Activity-based, project-based, and problem-based learning (APPB-learning) is core to the curriculum philosophy that guides the curricula development produced by Project Lead The Way, Inc. Gathering information about the level of rigor and relevance of activities, projects, and problems with a science and mathematics emphasis will also be useful to ongoing efforts to maintain a high level of quality in the curricula developed by Project Lead The Way, Inc. Additionally, this data may be compared with the data for the performance objectives to determine the degree to which the rigor and relevance of the activities, projects and problems in the course align with the rigor and relevance of the content as identified in the course objectives.

Conclusion

It is apparent that the United States is lagging behind in our efforts to educate enough young people to fill the ever-increasing pipeline of necessary science, technology, engineering, and mathematics (STEM) talent that is demanded by business and industry in order to sustain economic growth. Research continues to point to the role high-rigor, high-relevance curricula can play in addressing this issue (Daggett, 2005). In order to curtail this issue, steps must be taken to ensure shared accountability for the design and development of high-rigor, high-relevance STEM curricula. This study was designed to address the need for a clear and consistent way to describe the rigor and relevance of a particular curriculum and to highlight the importance of providing a method that will enable different educational stakeholders a means to make decisions regarding instructional materials selected to meet the needs of students of STEM education. Currently, many curriculum development processes employ strategies to develop instructional and curriculum guides that define rigorous course objectives, outline the content to be covered, and provide opportunities for students to apply their newly acquired knowledge in relevant, real-world settings. It is our hope that this analysis method will be used to determine the level of rigor and relevance and ties to subjects, such as mathematics and science, in other STEM curricula. We believe this form of accountability for producing high-rigor, high-relevance curricula is an important component to our ongoing efforts to build a high quality and globally competitive STEM education system.

Appendix A

Detailed Depth of Knowledge Descriptions

Level 1 – Recall & Reproduction of Information or Procedures

Curricular elements that fall into this category involve basic tasks that require students to recall or reproduce knowledge and/or skills. The subject matter content at this particular level usually involves working with facts, terms and/or properties of objects. It may also involve use of simple procedures and/or formulas. There is little transformation or extended processing of the target knowledge required by the tasks that fall into this category. Key words that often denote this particular level include: list, identify and define. Example tasks at this particular level include:

- Basic calculation tasks involving only one step (i.e. addition, subtraction, etc)
- Tasks that engage students in locating or retrieving information in verbatim form
- Straight-forward recognition tasks related to identifying features, objects and/or steps that don't vary greatly in form (i.e. recognizing features of basic tools)
- Writing tasks that involve applying a standard set of conventions and or criteria that should eventually be automated (i.e. using punctuation, spelling, etc)
- Basic measurement tasks that involve one step (i.e. using a ruler to measure length)
- Application of a simple formula where at least one of the unknowns are provided
- Locating information in maps, charts, tables, graphs, and drawings

Level 2 – Working with Skills & Concepts

Elements found in a curriculum that fall in this category involve working with or applying skills and/or concepts to tasks related to the field of engineering in a predictable laboratory setting. The subject matter content at this particular level usually involves working with a set of principles, categories, heuristics, and protocols. At this level students are asked to transform/process target knowledge before responding. Example mental processes that often denote this particular level include: summarize, estimate, organize, classify, and infer. Some tasks that may fit at this particular level include:

- Routine application tasks (i.e. applying a simple set of rules or protocols to a laboratory situation the same way each time)
- Explaining the meaning of a concept and/or explaining how to perform a particular task
- Stating relationships among a number of concepts and or principles
- More complex recognition tasks that involve recognizing concepts and processes that may vary in how they "appear"
- More complex calculation tasks (i.e. multi-step calculations such as standard deviation)
- Research projects and writing activities that involve locating, collecting, organizing and displaying information (i.e. writing a report with the purpose to inform)
- Measurement tasks that occur over a period of time and involve aggregating/organizing the data collected in to basic presentation forms such as a simple table or graph

Level 3 – Short-term Strategic Thinking

Items falling into this category demand a short-term use of higher order thinking processes, such as analysis and evaluation, to solve real-world problems with predictable outcomes. Stating one's reasoning is a key marker of tasks that fall into this particular category. The expectation established for tasks at this level tends to require coordination of knowledge and skill from multiple subject-matter areas to carry out processes and reach a solution in a project-based setting. Key processes that often denote this particular level include: analyze, explain and support with evidence, generalize, and create. Some curricular and assessment tasks that require strategic thinking include:

- Short-term tasks and projects placing a strong emphasis on transferring knowledge to solve predictable problems
- Explaining and/or working with abstract terms and concepts
- Recognition tasks when the environment observed is real-world and often contains extraneous information which must be sorted through
- Complex calculation problems presented that draw upon multiple processes
- Writing and or explaining tasks that require altering a message to "fit" an audience
- Creating graphs, tables and charts where students must reason through and organize the information with instructor prompts
- Identifying a research question and/or designing investigations to answer a question
- Tasks that involve proposing solutions or making predictions

Level 4 – Extended Strategic Thinking

Curricular elements assigned to this level demand extended use of higher order thinking processes such as synthesis, reflection, assessment and adjustment of plans over time. Students are engaged in conducting investigations to solve real-world problems with unpredictable outcomes. Employing and sustaining strategic thinking processes over a longer period of time to solve the problem is a key feature of curricular objectives that are assigned to this level. Key strategic thinking processes that denote this particular level include: synthesize, reflect, conduct, and manage. Example tasks include:

- Applying information to solve ill-defined problems in novel situations
- Tasks that require a number of cognitive and psychomotor skills in order to complete
- Writing and/or research tasks that involve formulating and testing hypotheses over time
- Tasks that require students to make multiple strategic and procedural decisions as they are presented with new information throughout the course of the event
- Tasks that require perspective taking and collaboration with a group of individuals
- Creating graphs, tables and charts where students must reason through and organize the information without instructor prompts
- Writing tasks that have a strong emphasis on persuasion

Appendix B
Sample IED Course Objectives and DOK Level Assignments

DOK Level	Objective	Location
Level 1 *Recall/ Reproduction of Information or Procedures*	Identify common geometric shapes and forms by name.	Unit 2 Lesson 2.1 Performance Objective
	Students will list the elements of design.	Unit 3 Lesson 3.1 Assessment Objective
Level 2 *Working with Skills and Concepts*	Apply engineering notebook standards and protocols when documenting their work during the school year.	Unit 1 Lesson 1.1 Performance Objective
	Students will explain the difference between one-point, two-point, and three-point perspectives.	Unit 1 Lesson 1.2 Assessment Objective
Level 3 *Short-Term Strategic Thinking*	Apply geometric numeric and parametric constraints to form CAD modeled parts.	Unit 2 Lesson 2.4 Performance Objective
	Students develop a black box model to identify the inputs and outputs associated with a system.	Unit 3 Lesson 3.2 Assessment Objective
Level 4 *Extended Strategic Thinking*	Research and construct a product impact timeline presentation of a product from the brainstorming list and present how the product may be recycled and used to make other products after its lifecycle is complete.	Unit 4 Lesson 4.1 Performance Objective
	Students will apply the design process to solve a design problem within a virtual team.	Unit 4 Lesson 4.2 Assessment Objective

Appendix C –

Sample IED Objectives Emphasizing Mathematics and Science by DOK Level

DOK Level	Objective	Mathematics and/or Science Standard Link
Level 1 *Recall/ Reproduction of Information or Procedures*	Identify common geometric shapes and forms by name.	• *PSSM* Geometry Standard
	Students will list the elements of design.	• *PSSM Connections Standard* • *PSSM Geometry Standard*
Level 2 *Working with Skills and Concepts*	Apply engineering notebook standards and protocols when documenting their work during the school year.	• *PSSM Communication Standard* • *PSSM Representation Standard* • *NSES Content Standard A: Science As Inquiry*
	Explain the concept of fluid power, and the difference between hydraulic and pneumatic power systems	• *NSES Content Standard B: Physical Science*
Level 3 *Short-Term Strategic Thinking*	Apply geometric numeric and parametric constraints to form CAD modeled parts.	• *PSSM Geometry Standard* • *PSSM Algebra Standard* • *NSES Content Standard E: Science and Technology:*
	Students develop a black box model to identify the inputs and outputs associated with a system.	• *NSES K-12 Unifying Concepts: Form and Function* • *NSES Content Standard E: Science and Technology*
Level 4 *Extended Strategic Thinking*	Research and construct a product impact timeline presentation of a product from the brainstorming list and present how the product may be recycled and used to make other products after its lifecycle is complete.	• *NSES* Content Standard E: Science and Technology
	Students will apply the design process to solve a design problem within a virtual team.	• *PSSM Problem Solving Standard* • *NSES Content Standard E: Science and Technology*

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