Engineering

Curriculum

High School Program: Pathway to Engineering™

Project Lead The Way (PLTW) offers a dynamic high school program that provides students with real-world learning and hands-on experience. Students interested in engineering, biomechanics, aeronautics, and other applied math and science arenas will discover PLTW is an exciting portal into these industries.

The Applied Knowledge of Pathway To Engineering™

PLTW's premier high school program, Pathway To Engineering™, is a four-year course of study integrated into the students' core curriculum. The combination of traditional math and science courses with innovative Pathway To Engineering courses prepares students for college majors in engineering and E/T fields and offers them the opportunity to earn college credit while still in high school.

Pathway To Engineering™ courses engage high school students through a combination of activities-based, project-based, and problem-based (APPB) learning. APPB learning not only creates an environment for applying engineering concepts to real problems, but also prepares students to:

- Solve problems
- Participate as part of a team
- Lead teams
- Speak to a public audience
- Conduct research
- Understand real-world impacts
- Analyze data
- Learn outside the classroom

The Logic Skills behind the Three-Tiered Approach

Logical thought processes are built through APPB learning experiences in the program's three-tiered approach to coursework.

Tier One: Foundation

- **Introduction to Engineering Design™**—uses a design

Middle School Program: Gateway To Technology

Build...
...a robot
...a racecar
...a fantastic future

Gateway To Technology is the PLTW middle school course program. It is divided into five independent nine-week courses developed for grades six through eight. GTT is taught in conjunction with a rigorous academic curriculum and is designed to challenge and engage the natural curiosity of middle school students.

Gateway To Technology Courses

Design and Modeling (DM)
Students use geometry, problem-solving, teamwork, and project management skills to design and develop product prototypes.

The Magic of Electrons (ME)
Engaged in relevant hands-on projects, students unravel the mysteries of digital circuitry.

The Science of Technology (ST)
Students apply scientific principles and concepts of simple machines and energy to solve real-world problems.

Automation and Robotics (AR)
Students design and build automated systems that incorporate the principles of electrons, physics, and robotics to gain an enriched understanding of the contemporary mechanical world.

Flight and Space (FS)
Developed with NASA, this unit explores the technology of aeronautics, propulsion, and rocketry. Students see connections between hands-on projects and academic subjects such as math and science.

GTT harnesses the enthusiasm and energy of middle school students. The program focuses on showing, not telling, students how to use engineering skills to solve everyday problems. Students won't ask, "Will I ever have to use this in real life?" because they will be applying their skills as they learn them. The primary focus is on stronger math, science, and technology inquiry skills.

development process while enriching problemsolving skills; students create and analyze models using specialized computer software.

- **Principles Of Engineering™**—explores technology systems and manufacturing processes; addresses the social and political consequences of technological change.

- **Digital Electronics™**—teaches applied logic through work with electronic circuitry, which students also construct and test for functionality.

Tier Two: Specialization Courses

- **Aerospace Engineering™**—expands horizons with Projects developed with NASA- aerodynamics, astronautics, space-life sciences, and systems engineering.

- **Biotechnical Engineering™**—hones more advanced skills in biology, physics, technology, and mathematics and applies them to real-world biotech fields.

- **Civil Engineering and Architecture™**—introduces students to the interdependent fields of civil engineering and architecture; students learn project planning, site planning, and building design.

- **Computer Integrated Manufacturing™**—enhances computer modeling skills by applying principles of robotics and automation to the creation of models of three-dimensional designs.

Tier Three: Capstone Course

Engineering Design and Development™ is a research course that requires students to formulate the solution to an open-ended engineering question. With a community mentor and skills gained in their previous courses, students create written reports on their applications, defend the reports, and submit them to a panel of outside reviewers at the end of the school year.

Endless Possibilities

High school students involved in PLTW strive to complete a minimum of the three foundation courses, one specialization course, and the capstone course. The Pathway To Engineering system works in any standard four-year sequence and prepares students for two- or four-year college studies in engineering and E/T by exposing them to the true scope of the field. Most courses can earn course credit at accredited colleges and universities.

No matter where students pursue their collegiate training in engineering, Project Lead The Way provides an excellent foundation for addressing and implementing real solutions to real problems with contemporary technology and applied logic.

Introduction to Engineering Design™

Analysis of Cognitive Levels of Learning and Mathematics and Science Content

2008

Project Lead The Way, Inc.

Clifton Park, NY

Project Lead The Way® Curricula: Helping all students reach for rigor and relevance

Preface

The terms science, technology, engineering, and mathematics or STEM is an acronym we have all come to know and understand. The fact the four terms are used in a single idea implies that the four subject matters are also taught as an integrated whole. However, that is not the case. With the exception of early childhood experiences, most K-16 courses are taught within their individual academic curriculum with like-minded colleagues asking why their students don't make the connections. The need to tear away the barriers, which will enable all teachers to educate and "engage" students, requires looking at the system in a different way. To do so, much must be accomplished with research that supports the process and enhances the learning and success of all students through appropriate learning and teaching styles.

The need to show the relevance and interconnectedness to what students are learning is more important than ever in order to excite, not only the top 10% of students, but each student within a school population.

The mission of Project Lead The Way, Inc. is to create dynamic partnerships with our nation's schools to prepare an increasing and more diverse group of students to be successful in science, mathematics, engineering, and engineering technology

Goal Two from the seven goals of the Project Lead The Way® Strategic Plan II highlights this commitment.

> **Goal Two**
> To ensure the inclusion and success of all groups of students, Project Lead The Way, Inc. will implement a continuous improvement process to update and maintain the Project Lead The Way® curriculum to meet national college readiness and national learning standards.

Exciting all students cannot be achieved without captivating student interest in STEM. Captivating student interest requires being relevant to students' lives and at the same time rigorous in such a way that students are not threatened or turned off by misconceptions, such as they cannot do science or mathematics. Within the current academic structure for the delivery of STEM content, students are not always afforded the opportunities to discover that they really can achieve high-level learning with rigor. Thus, Project Lead The Way® curricula is written to bridge the gap between those students who can and those who do not know they can learn to work in the fields of engineering and engineering technology.

This report highlights to what extent the Project Lead The Way® curricula works to help teachers achieve the goals of reaching all students and giving all students experiences that will enable them to make decisions regarding their future careers in engineering and engineering technology fields.

Table of Contents

Report Overview

Project Lead the Way (PLTW) approached Vivayic, Inc. to conduct a review of selected courses within the existing curriculum as neutral third party. The purpose of the curriculum review is to provide externally generated data to help PLTW leadership understand the extent to which the present curriculum matches various aligns with the "advertised" level of rigor and relevance.

Following an initial review of sample PLTW course materials Vivayic proposed several report options to meet the stated need. Webb's (1997) model for evaluating alignment among standards, assessment and curriculum provides base metrics to be used in collecting and analyzing the data for each report.

PLTW leadership elected to complete a depth of knowledge analysis on the Introduction to Engineering Design course for high school students. *The analysis is intended to provide feedback to PLTW leaders regarding the relative level of cognitive rigor promoted, as established in the course objectives.* The following pages detail the results of this analysis.

Primary Investigation Question

At what level of cognitive rigor are students expected to "perform" throughout the PLTW Introduction to Engineering Design course?"

General Procedure

To answer this question the performance and assessment objectives stated in the course lesson plans were used as a proxy for what is cognitively expected of students. Each objective was assigned a numeric value from Webb's (1997, 2002) Depth of Knowledge Levels, a model created to categorize the level of cognitive demand required by curricular elements. Numeric values assigned to each level were analyzed using descriptive statistics to produce a picture of the relative level of cognitive expectations reflected in the course. The findings and points for future discussion are provided following a discussion of the specific methods used.

Overview of Cognitive Expectation Model Used

Webb (1997) developed a process and criteria for systematically analyzing the alignment between standards and standardized assessments. Since then the process and criteria have demonstrated application to reviewing curricular alignment as well. This body of work offers the Depth of Knowledge (DOK) model employed to analyze the cognitive expectation demanded by standards, curricular activities and assessment tasks (Webb, 1997). The model is based upon the assumption that curricular elements may all be categorized based upon the cognitive demands required to produce an acceptable response. Each grouping of tasks reflects a different level of cognitive expectation, or depth of knowledge, required to complete the task. It should be noted that the term knowledge, as it is used here, is intended to broadly encompass all forms of knowledge (i.e. procedural, declarative, situative, etc.). The following table reflects an adapted version of the model.

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

This model was selected as a base for use in this inquiry for three reasons:

- *It can help answer the question, "What exists?" rather than, "What should be?"* - The Depth-of-Knowledge model can be used as a tool to give a "picture" of the cognitive expectations as they currently exist. The model remains neutral as to what level of cognitive expectation *should* be reflected in the curricular elements – that is a decision for the leaders in charge of the curriculum to make.

- *Focused on Evaluation not Development* - The model was created with the intent of *evaluating* the cognitive expectations demanded by curricular elements. Other taxonomies offer additional levels of specificity that make them more useful in guiding *development* of curricula (i.e. Bloom's Taxonomy).

- *Lays a Foundation for Further Analysis* - Conducting a Depth-of-Knowledge analysis provides foundational data that may be used to further inspect the alignment throughout the course using additional criteria outlined by Webb (1997).

Detailed Procedures

Step 1 – Defining the DOK Levels for the Analysis

To use the model in this analysis the four DOK levels were defined further. Webb's (2002) definitions of the Depth of Knowledge levels for Science, Mathematics and Language Arts served as a base for the this analysis. Input from experts in the field of engineering was used to further 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. The definitions below represent the model used to assign a level, one thru four, to each objective in the Introduction to Engineering Design course.

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 physical 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

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/are not sufficient information to assign a DOK level. Evaluators must also consider the complexity of the task and/or 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 2 – Completing Initial DOK Level Assignments to All 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. 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 better understand the level of expectation for "satisfactory attainment" the reviewer used the IED course materials to further investigate the nature of the content, the instructional treatments used and the assessment rubrics related to the 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.

Step 3 – Checking the Accuracy of Initial DOK Level Assignments

A sample of 33 randomly selected course objectives (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 further 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: $\kappa = 0.41$ to 0.60 reflects moderate inter-rater agreement, $\kappa=0.61$ to 0.80 substantial and $\kappa=0.81$-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 $\kappa=0.75983$ ($P<0.000$). This represents a level of agreement significantly different ($\alpha=.05$) 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 ($\alpha=.05$) 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 ($\kappa=1$, $P<0.000$). The source of disagreement between the evaluators was mostly found with assignment of Levels 2 & 3 ($\kappa=0.67836$ and $\kappa=0.69274$, $P=0.000$ 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. Attachment A contains a sample of the objectives showing the DOK level to which they were assigned.

Step 4 – Conducting Data Compilation and Analysis

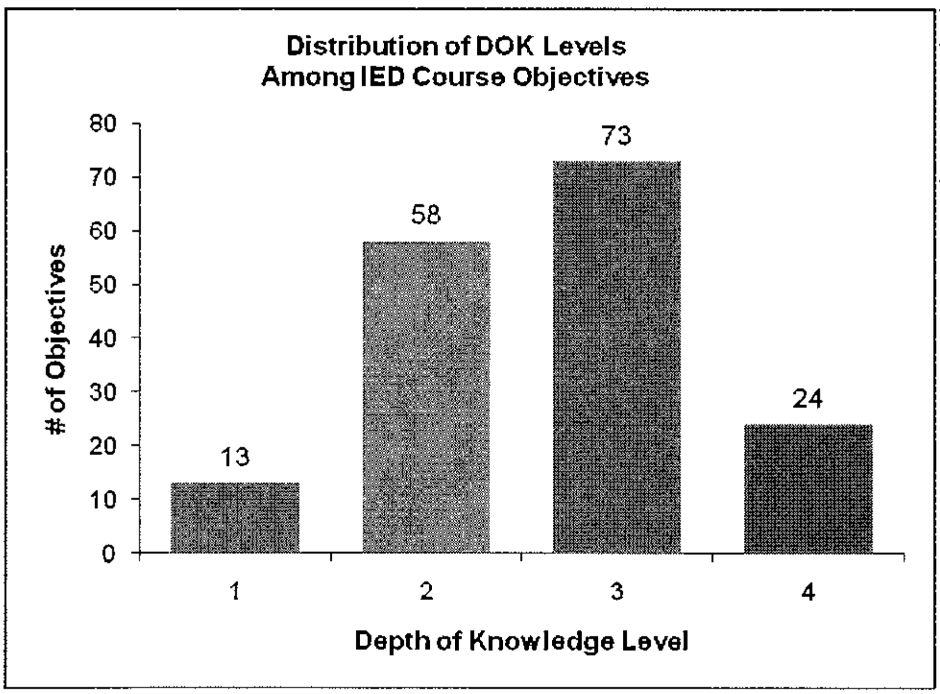
Once the task of assigning levels to each objective was complete final data analysis began. Given the original question for this investigation descriptive statistics were chosen as the primary vehicle to analyze the data. First, a series of histograms were created to show how often the four levels occurred throughout the curriculum. These charts were created at the course level and the unit level. Performance and assessment objectives were also broken apart at each level. Assessment objectives were also re-organized into a series of histograms based upon the six facets of understanding. This was done in order to review the distribution of DOK levels among each facet as this is an important underlying element of the course design. In addition to the histograms other measures of central tendency such as mean, median, mode and standard deviation are provided to assist reviewers of this report in understanding the relative level of cognitive expectations distributed among the course objectives.

Results

The following charts and tables represent the results of the DOK Analysis on the IED course. A summary of general trends and points for discussion is located in the discussion section. A table containing examples of course objectives and the DOK level assigned is located in Attachment A.

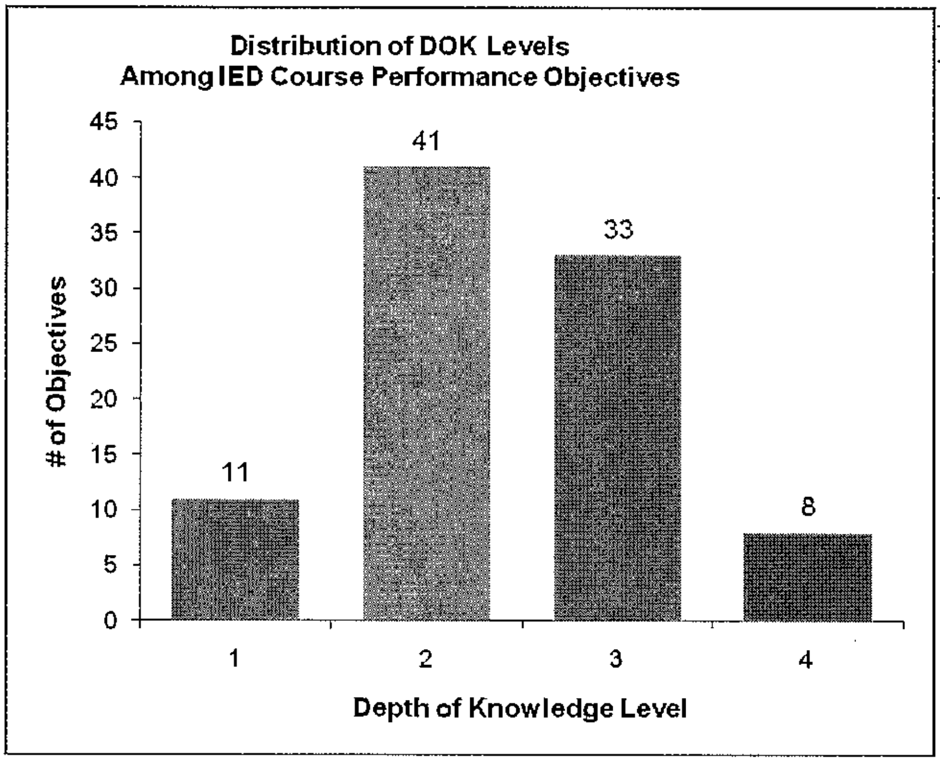
Overall Course Analysis

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

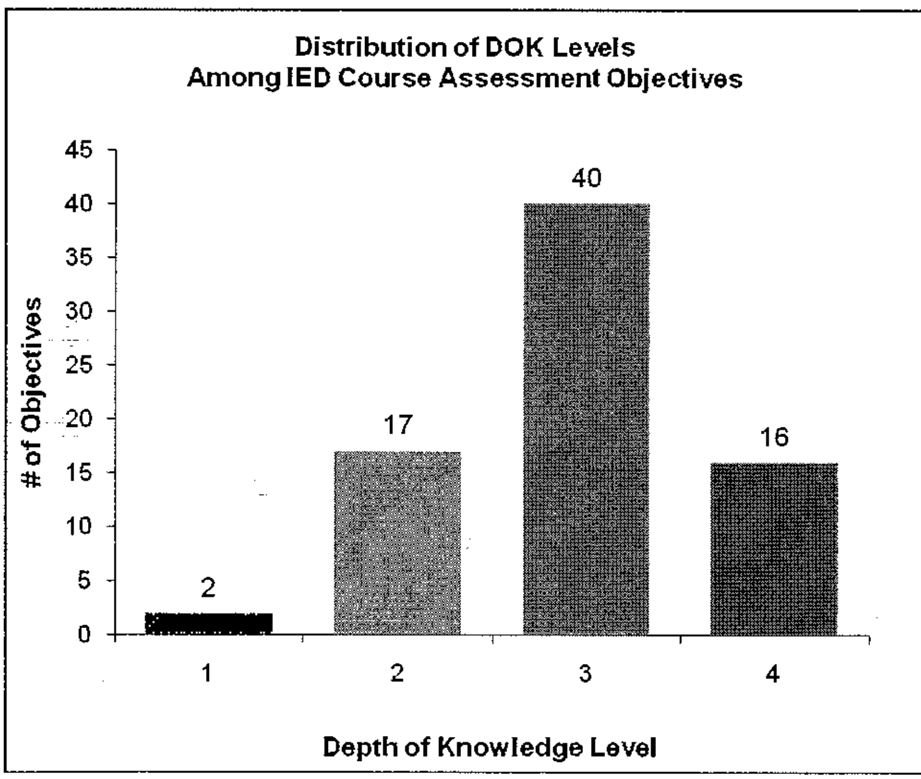
All Performance Objectives



DOK Level	*Frequency*
1	11
2	41
3	33
4	8
Count	93
Mean	2.41
Mode	2
SD	0.811
Median	2.00

*SD=standard deviation

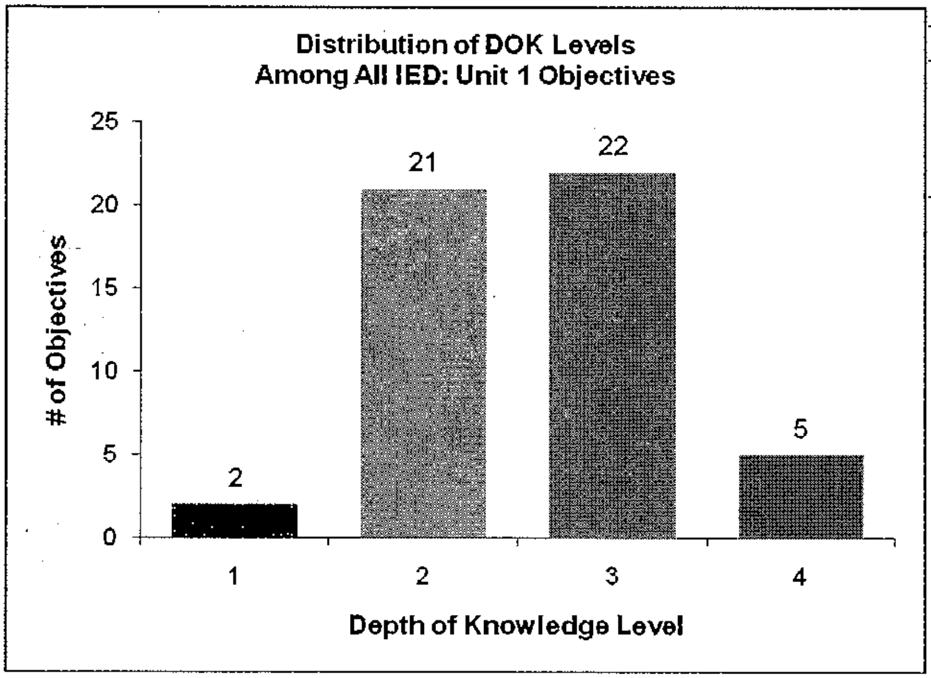
All Assessment Objectives



DOK Level	*Frequency*
1	2
2	17
3	40
4	16
Count	75
Mean	2.93
Mode	3
SD	0.741
Median	3.00

Unit 1 Analysis

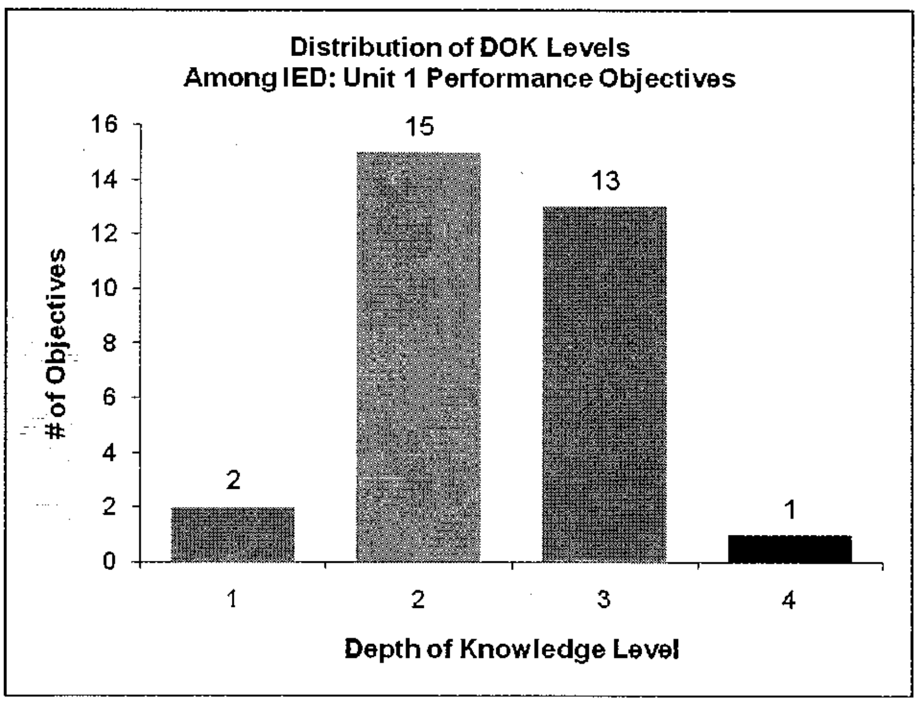
All Unit 1 Objectives



DOK Level	Frequency
1	2
2	21
3	22
4	5

Count	50
Mean	2.6
Mode	3
SD	0.728
Median	3

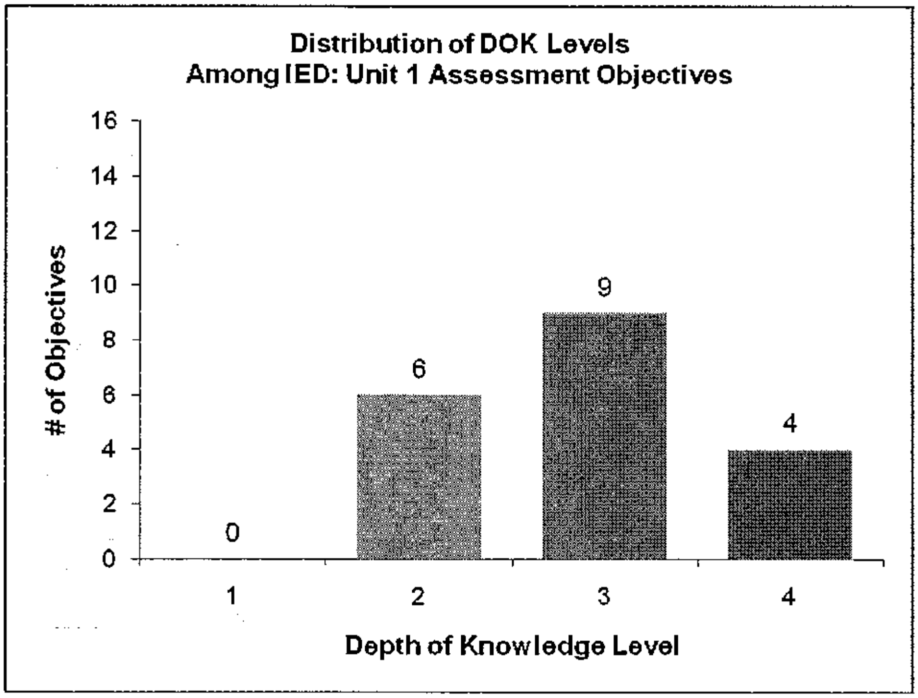
Unit 1 Performance Objectives



DOK Level	Frequency
1	2
2	15
3	13
4	1

Count	31
Mean	2.42
Mode	2
SD	0.672
Median	2.00

Unit 1 Assessment Objectives

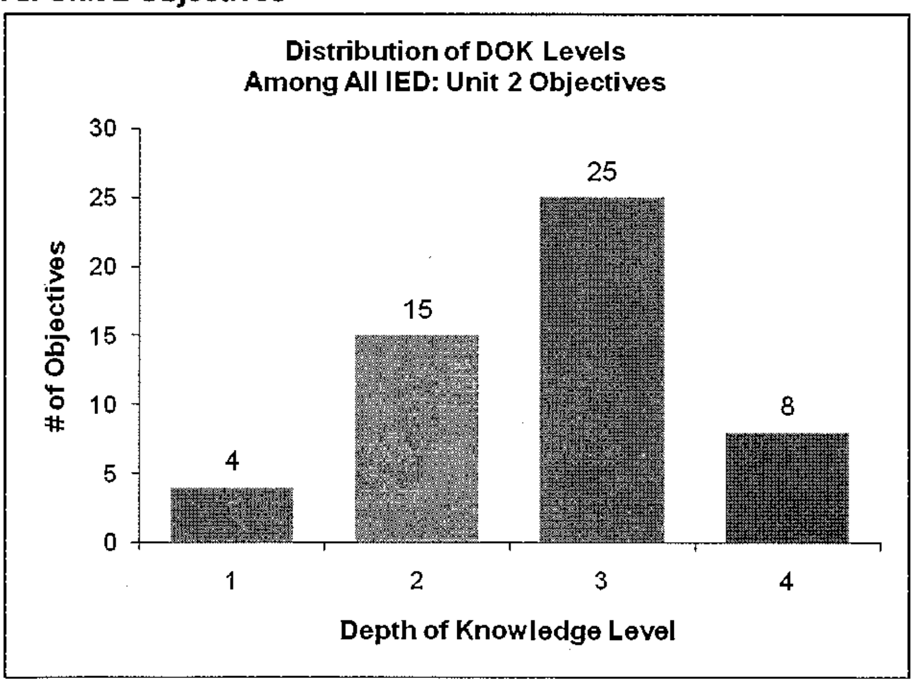


DOK Level	Frequency
1	2
2	15
3	13
4	1

Count	19
Mean	2.89
Mode	3
SD	0.737
Median	3.00

Unit 2 Analysis

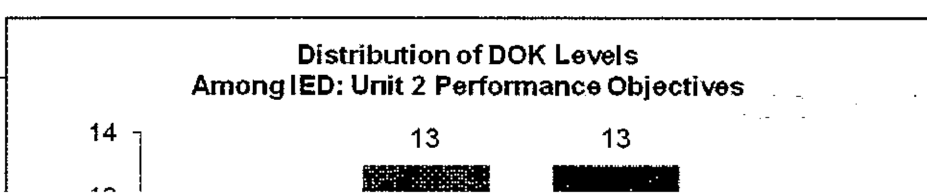
All Unit 2 Objectives



DOK Level	Frequency
1	4
2	15
3	25
4	8

Count	52
Mean	2.71
Mode	3
SD	0.825
Median	3

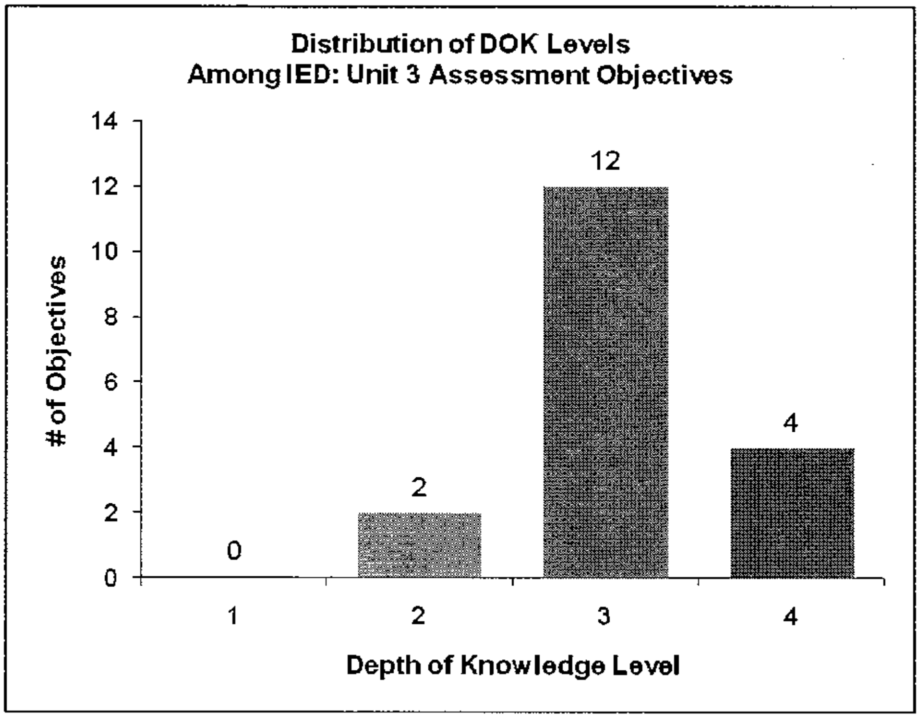
Unit 2 Performance Objectives



DOK Level	*Frequency*
1	4
2	13
3	13
4	4

Count	34
Mean	2.5
Mode	2,3
SD	0.862
Median	2.5

Unit 2 Assessment Objectives

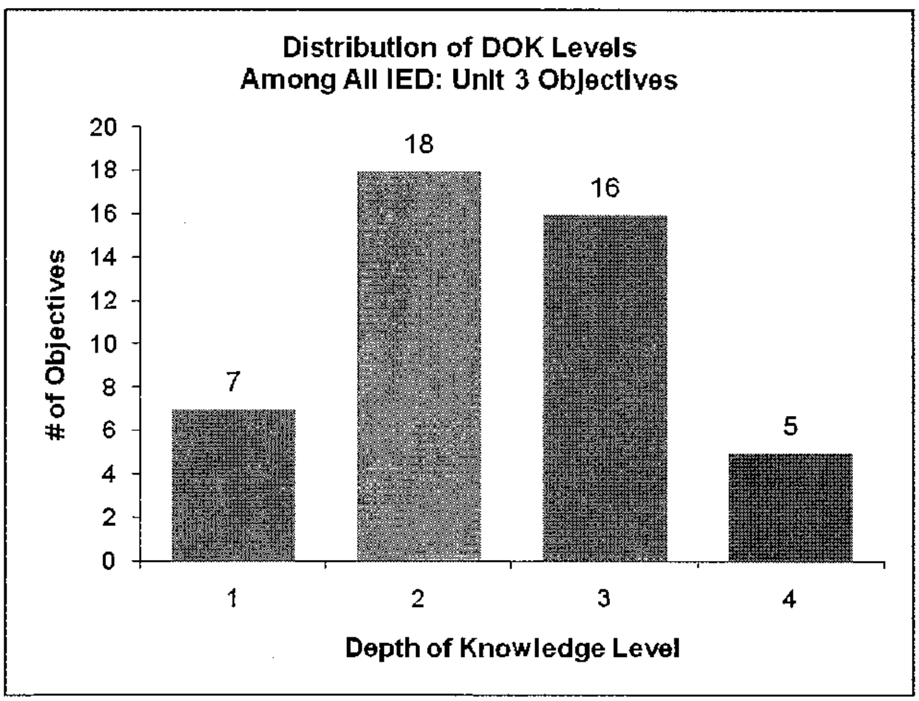


DOK Level	Frequency
1	0
2	2
3	12
4	4

Count	18
Mean	3.11
Mode	3
SD	0.583
Median	3.00

Unit 3 Analysis

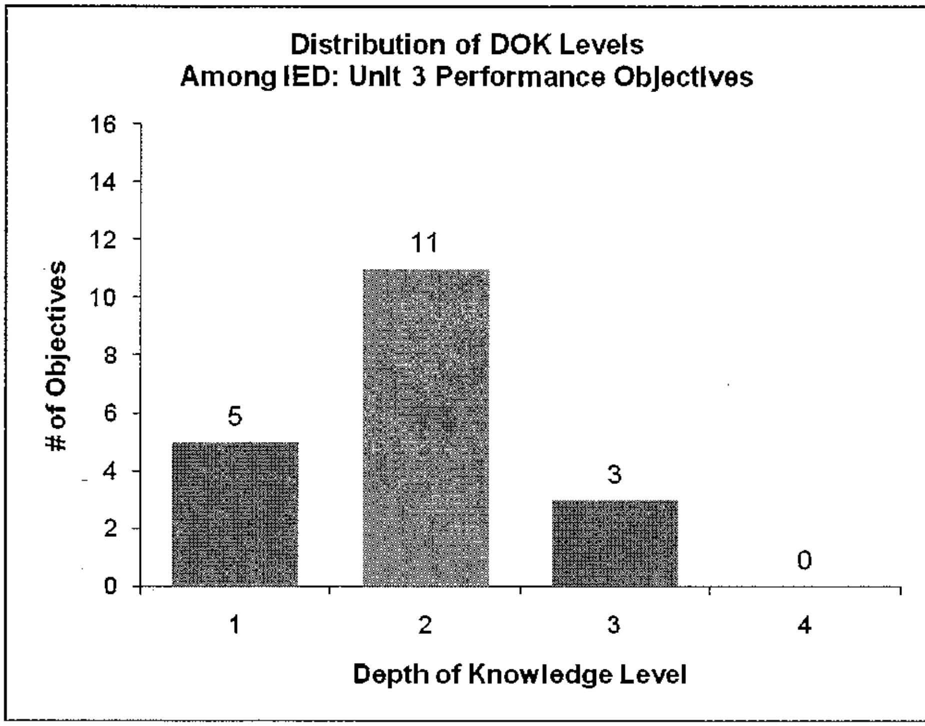
All Unit 3 Objectives



DOK Level	Frequency
1	7
2	18
3	16
4	5

Count	46
Mean	2.41
Mode	2
SD	0.884
Median	2

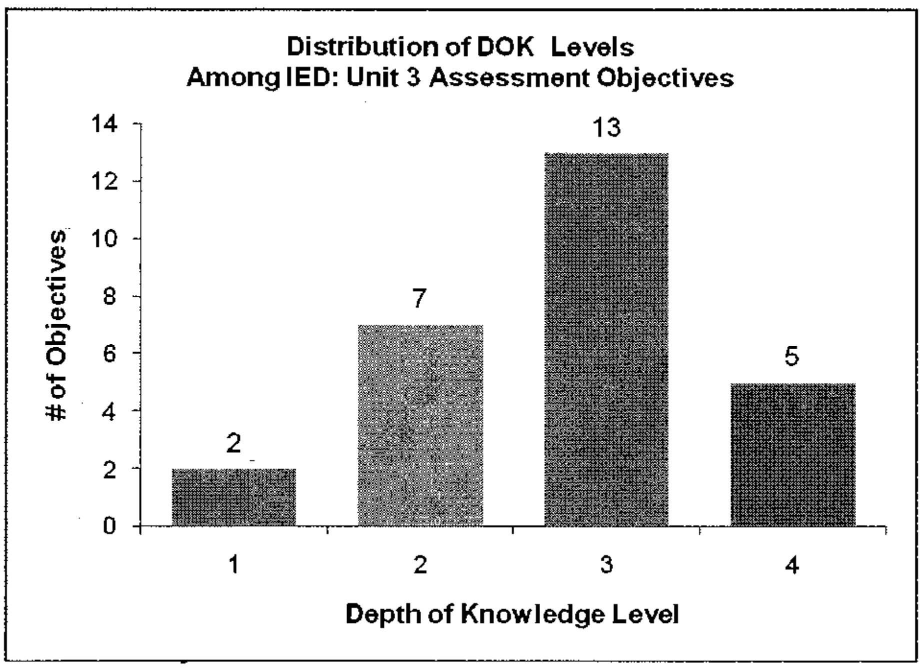
Unit 3 Performance Objectives



DOK Level	*Frequency*
1	5
2	11
3	3
4	0

Count	19
Mean	1.89
Mode	2
SD	0.658
Median	2.00

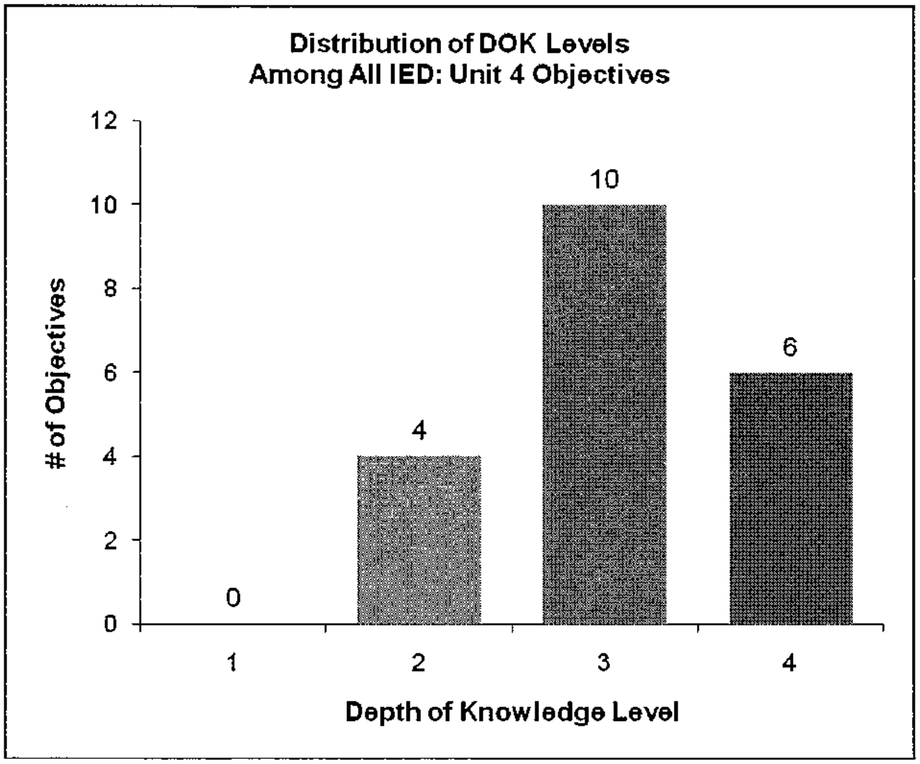
Unit 3 Assessment Objectives



DOK Level	*Frequency*
1	2
2	7
3	13
4	5

Count	27
Mean	2.78
Mode	3
SD	0.847
Median	3.00

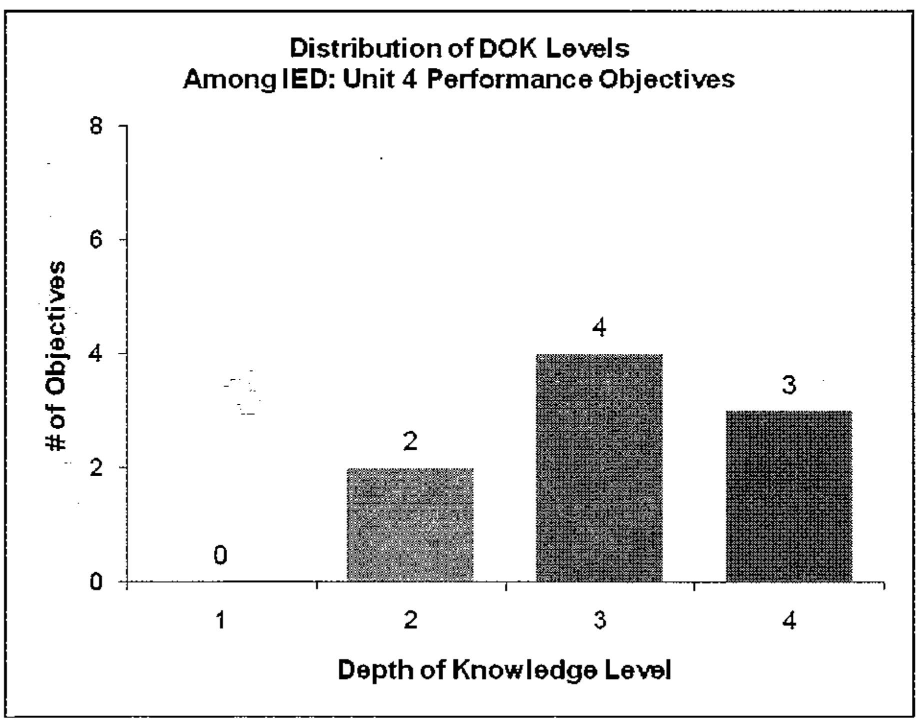
All Unit 4 Objectives



DOK Level	Frequency
1	0
2	4
3	10
4	6

Count	20
Mean	3.1
Mode	3
SD	0.718
Median	3

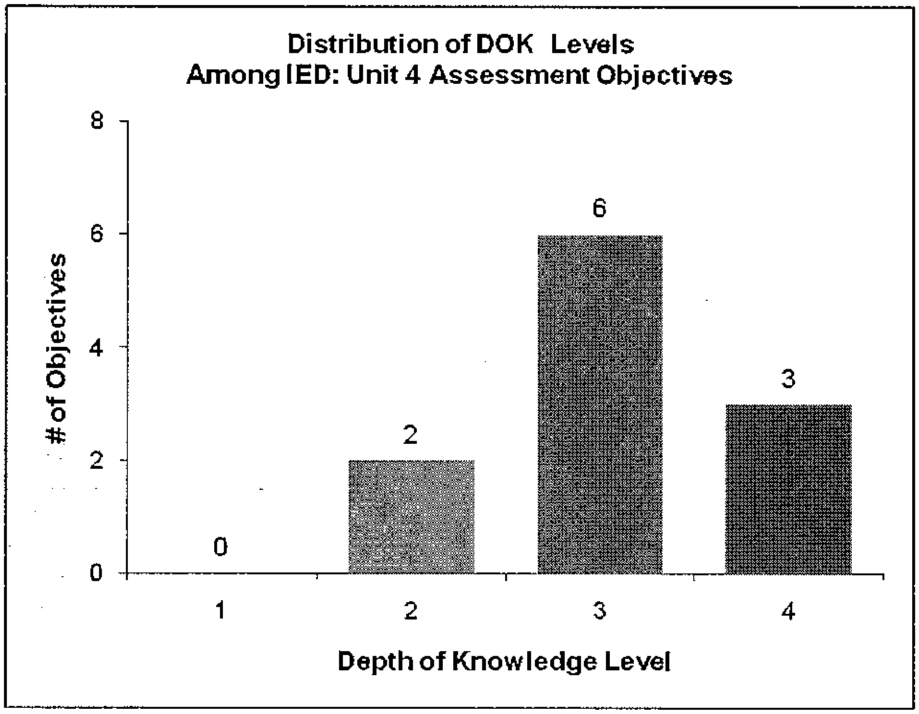
Unit 4 Performance Objectives



DOK Level	Frequency
1	0
2	2
3	4
4	3

Count	9
Mean	3.11
Mode	3
SD	0.782
Median	3.00

Unit 4 Assessment Objectives

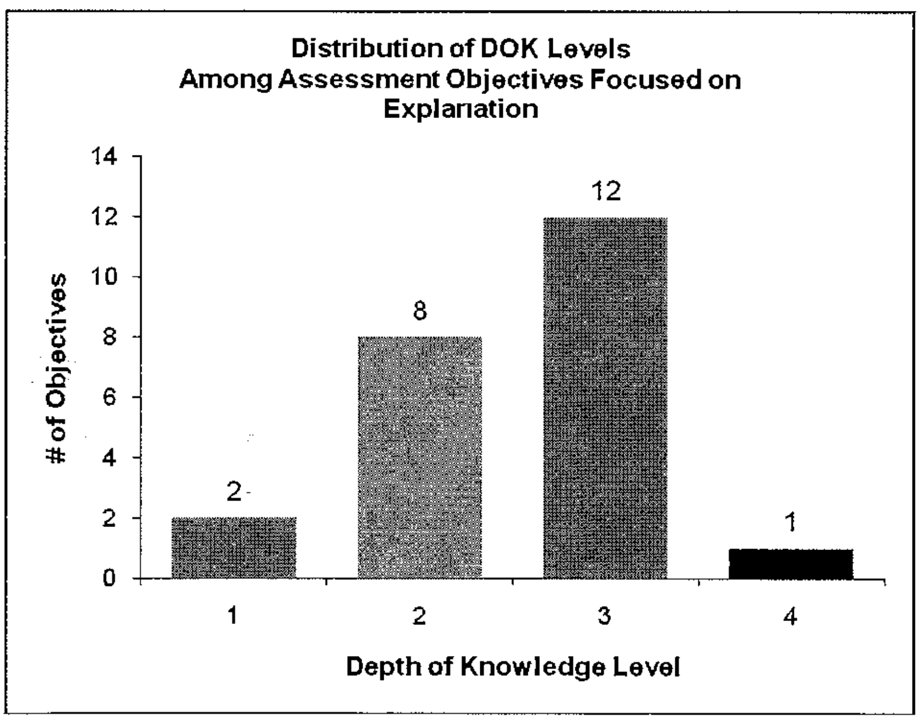


DOK Level	Frequency
1	0
2	2
3	6
4	3

Count	11
Mean	3.09
Mode	3
SD	0.701
Median	3.00

Assessment Objectives by Six Facets of Understanding

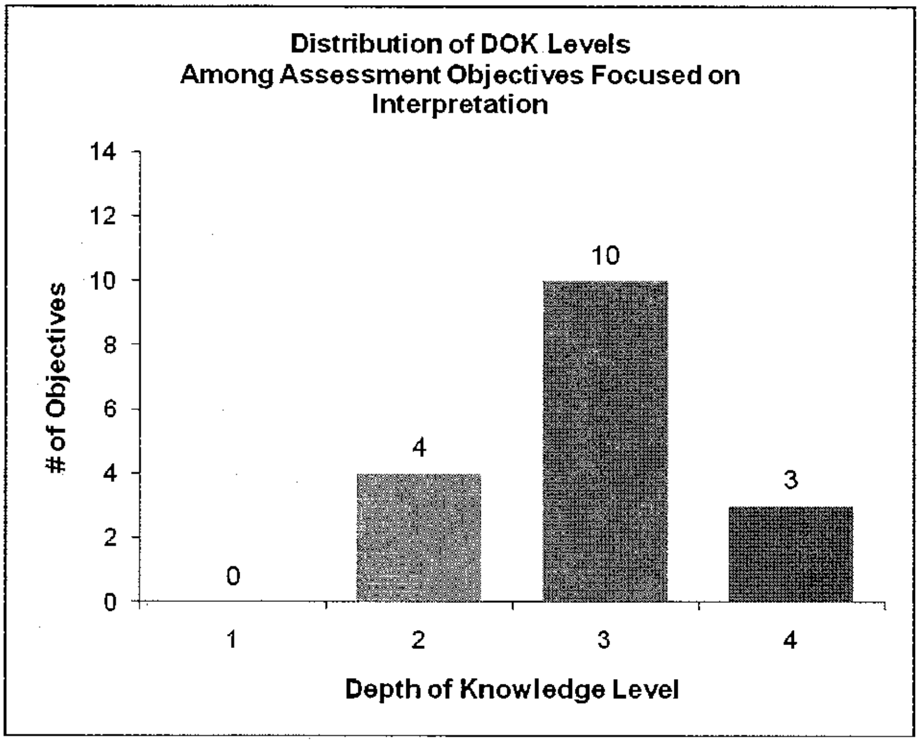
Explanation



DOK Level	Frequency
1	2
2	8
3	12
4	1

Count	23
Mean	2.43
Mode	3
Median	3
SD	0.728

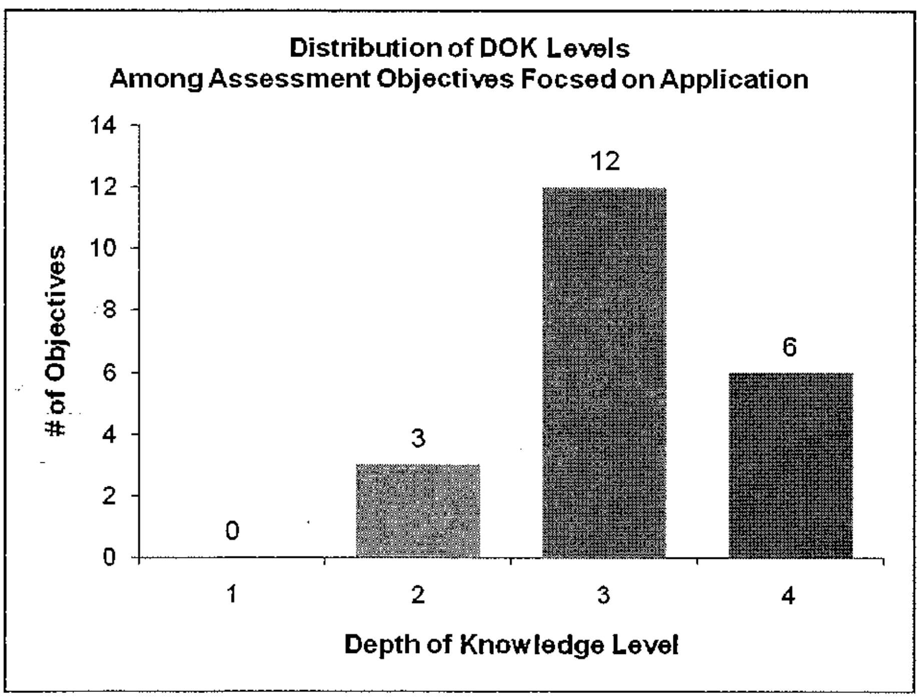
Interpretation



DOK Level	*Frequency*
1	0
2	4
3	10
4	3

Count	17
Mean	2.88
Mode	3
Median	3
SD	0.697

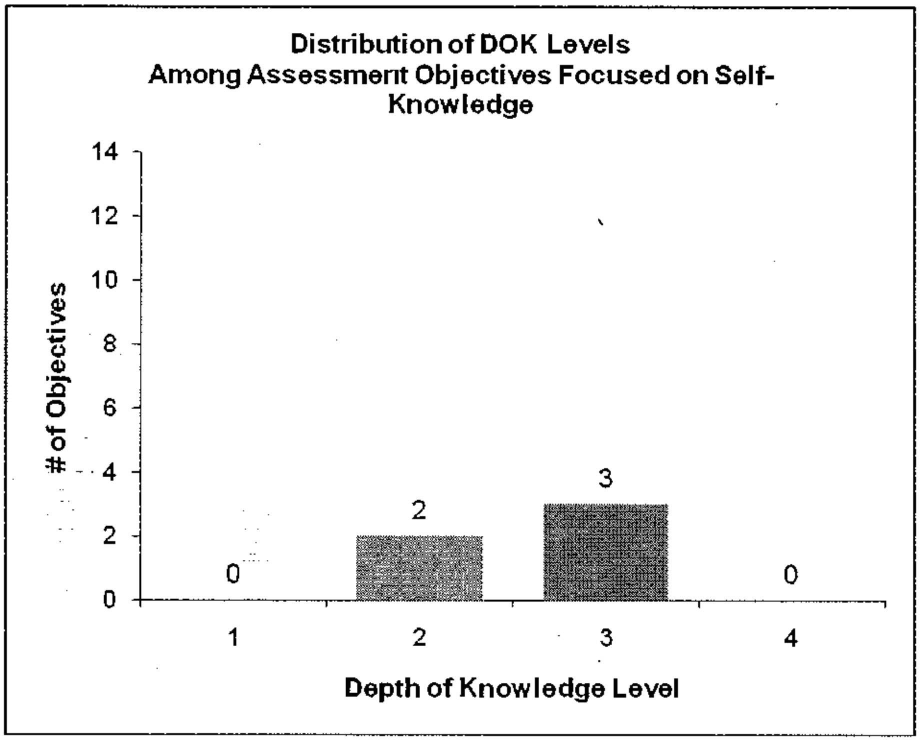
Application



DOK Level	*Frequency*
1	0
2	3
3	12
4	6

Count	21
Mean	3.05
Mode	3
Median	3
SD	0.590

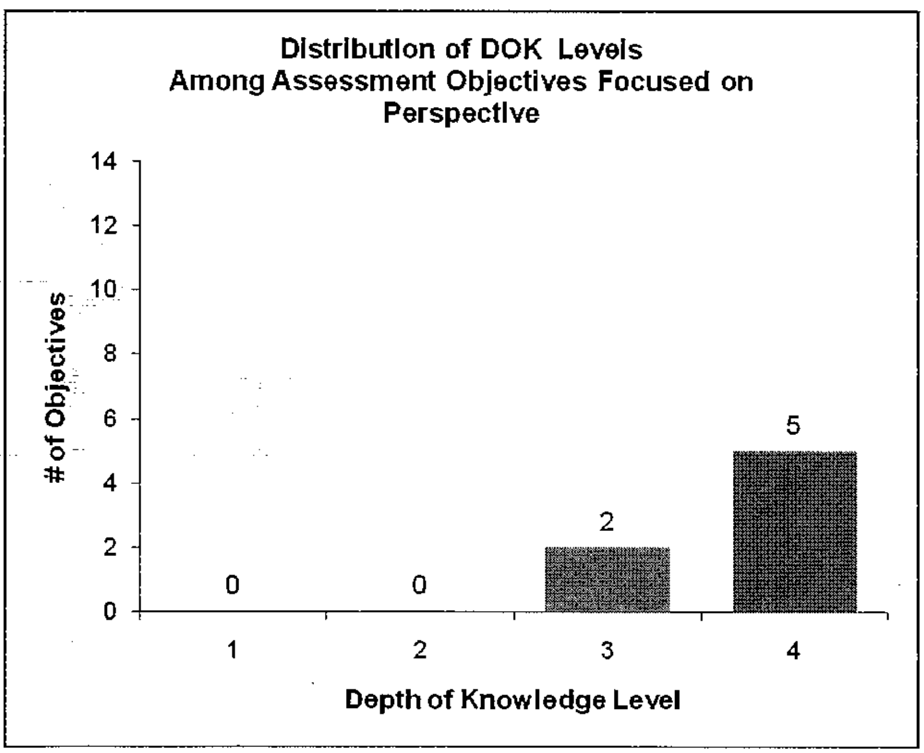
Self-Knowledge



DOK Level	Frequency
1	0
2	2
3	3
4	0

Count	5
Mean	2.60
Mode	3
Median	3
SD	0.548

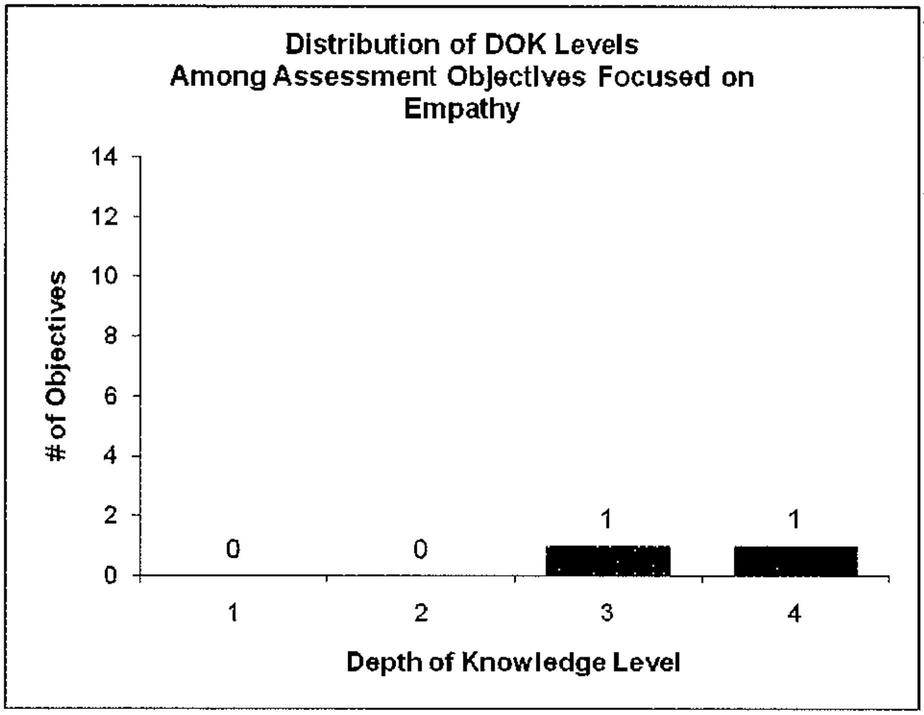
Perspective



DOK Level	Frequency
1	0
2	0
3	2
4	5

Count	7
Mean	3.71
Mode	4
Median	4
SD	0.488

Empathy



DOK Level	Frequency
1	0
2	0
3	1
4	1
Count	2
Mean	3.5
Mode	3,4
Median	3.5
SD	0.707

Discussion

General Observations

The primary question for this investigation was, "At what cognitive level are students expected to 'perform' throughout the PLTW Introduction to Engineering Design course?" The following points reflect some general responses afforded by this analysis:

1) *Generally, the data supports that students are most often expected to use short-term strategic thinking processes to meet the curricular objectives (Course Objective Mode=Level 3).*

    - 43.45% of the stated objectives demanded use of short-term strategic thinking
    - 34.52% of the objectives engage students in working with concepts and/or skills
    - 14.29% of the course objectives call for the use of extended strategic thinking
    - 7.74% of the objectives reviewed place emphasis on recall or reproduction

2) *Generally, the course performance objectives have a stronger emphasis on working with skills and concepts, level 2, and short-term strategic thinking, level 3. Assessment*

objectives tended to place a stronger emphasis on integration of skills and concepts through short-term strategic, level 3, and extended strategic thinking, level 4.

- 44.09% of the performance objectives were assigned to level 2. An additional 35.48% of objectives were assigned to level 3 indicating an emphasis on working with skills and concepts and short-term strategic thinking as part of the instructional focus.

- 53.33% of the assessment objectives (usually reflecting projects included in the curriculum) were assigned to level 3, short-term strategic thinking. An additional 21.33% of assessment objectives were at level 4.

3) *Objectives in units 1 through 3 reflected cognitive rigor that spanned all four levels in the DOK model. Emphasis in all three units falls primarily at levels 2 and 3. Unit 4 objectives placed more emphasis on short-term strategic and extended strategic thinking.*

- 50% of the objectives in Unit 4 were assigned to level 3, short-term strategic thinking. In addition, 30% of those objectives were assigned to level 4, extended strategic thinking.

- Unit 1 objectives place a near equal emphasis with 42% assigned to level 2, working with concepts and skills, and 44% assigned to level 3, short-term strategic thinking.

- 48.08% of unit 2 objectives place an emphasis on level 3, short-term strategic thinking.

- Unit 3 objectives also placed a near equal emphasis on levels 2 and 3 with 39.13% assigned to level 2, working with concepts and skills, and 34.78% assigned to level 3, short-term strategic thinking.

4) *Generally, the cognitive expectations set forward in the assessment objectives align with the rigor of thinking processes espoused by Wiggins & McTighe's (2005) six facets of understanding.*

- 52.17% of the explanation oriented objectives were assigned to level 3

- 58.82% of the interpretation oriented objectives were assigned to level 3

- 57.14% of the application oriented objectives were assigned to level 3

- 60% of the self-knowledge oriented objectives were assigned to level 3

- 71.43% of the perspective focused objectives were assigned to level 4

- 50% of the empathy oriented objectives were assigned to level 3

Points for Future Discussion

The following questions are provided as potential points of discussion among those who work with the PLTW course development and administration. The questions posed are based upon this particular analysis and provide future directions for additional inquiry.

1) *What is an optimal distribution of performance and assessment objectives at each of the four DOK levels in order to maximize learning retention, transfer and motivation?*

   The DOK model helps us to understand what level of cognitive rigor exists within a curriculum or a set of standards. The model however should not be taken to suggest that one level is preferred over another. Investigating what distribution(s) of performance and assessment tasks at various DOK levels constitutes an optimal level of cognitive rigor to promote student learning is a worthy discussion for the PLTW curriculum developers.

2) *In what ways is student learning influenced when performance objectives (instructional focus) predominantly demand different levels of cognitive processes than the related assessment objectives?*

   Throughout all four units the assessment objectives tended to reflect a higher level of cognitive rigor than the performance objectives. More information is needed to determine how this variance may influence student learning. For instance, it is assumed that there is a relationship between the cognitive rigor of the instruction as reflected in the performance objectives and the students satisfactory attainment of the expectations established in the assessment objectives. Thus, it may be useful to know how learning is influenced when the two sets of expectations do happen to differ in a significant way.

3) *In what ways does the cognitive rigor of the course objectives align with the cognitive rigor of the standards to which this curriculum has been aligned?*

   A similar analysis could be performed with the standards to which the curriculum has been aligned. Using this analysis and other criteria established by Webb (1997) one could begin to better describe the nature of the relationship between the course and the larger educational standards it meets.

4) *In what ways does the cognitive rigor of the course objectives align with the rigor demanded by the learning activities, projects, problems, and other related assessments?*

Often, objectives serve as guides in the instructional development process. It is important to consider the alignment between the cognitive expectations espoused in the objectives and the actual learning treatments and assessment created to assist students in their attainment. Further analysis using this report as a basis and additional metrics could reveal information regarding the alignment throughout the curriculum which may inform future instructional development efforts and/or a course revision process.

Appendix: Report Overview

This is an appendix to a Depth of Knowledge (DOK) analysis conducted on the Introduction to Engineering Course (IED) in December 2007. This report provides an analysis of the original data with an eye toward objectives that emphasize mathematics and science.

Appendix Investigation Question

What level of cognitive expectation is reflected in the IED course objectives emphasizing mathematics and science knowledge and skill?

General Procedure

To answer this question the performance and assessment objectives stated in the course were used as a proxy for what is cognitively expected of students. All course objectives were reviewed to identify those objectives that most emphasized mathematics and/or science concepts and skills. Nationally recognized standard frameworks for both Science and Mathematics were used to guide the categorization process. In the original analysis each course objective was assigned a score using Webb's (1997, 2002) Depth of Knowledge (DOK) model. To answer the investigation question, the DOK levels assigned to objectives placing an emphasis on mathematics or science were analyzed using descriptive statistics. The findings are provided following a discussion of the specific methods used.

Brief Overview of Cognitive Expectation Model Used

An in-depth overview of the model used in the initial analysis is outlined earlier in this paper. This brief overview is provided to re-establish context regarding the model used to develop this appendix to the original report.

Webb (1997) developed a process and criteria for systematically analyzing the alignment between standards and standardized assessments. Since then the process and criteria have demonstrated application to reviewing curricular alignment as well. This body of work offers the Depth of Knowledge (DOK) model employed to analyze the cognitive expectation demanded by standards, curricular activities and assessment tasks (Webb, 1997).

Overview of Mathematics and Science Standards

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 the *Principles and Standards for School Mathematics* as published by the National Council of Teachers of Mathematics (NCTM). Science concepts are defined by the *National Science Education Standards* as published by the National Research Council (NRC).

The following lists reflect the standards used for this analysis. A summary of the content standards follows.

National Science Education Standards

NSES Content Standard K-12: Unifying Concepts and Processes
As a result of activities in grades K-12, all students should develop understanding and abilities aligned with the following concepts and processes—

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Evolution and equilibrium
- Form and function

NSES Content Standard A: Science as Inquiry
As a result of activities in grades 9-12, all students should develop—

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

NSES Content Standard B: Physical Science
As a result of activities in grades 9-12, all students should develop an understanding of—

- Structure of atoms
- Structure and properties of matter
- Chemical reactions
- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

NSES Content Standard C: Life Science
As a result of activities in grades 9-12, all students should develop an understanding of—

- The cell
- Molecular basis of heredity
- Biological evolution
- Interdependence of organisms
- Matter, energy, and organization in living systems
- Behavior of organisms

NSES Content Standard D: Earth and Space Science
As a result of activities in grades 9-12, all students should develop an understanding of—

- Energy in the earth system
- Geochemical cycles
- Origin and evolution of the earth system
- Origin and evolution of the universe

NSES Content Standard E: Science and Technology
As a result of activities in grades 9-12, all students should develop—

- Abilities of technological design
- Understandings about science and technology

NSES Content Standard F: Science in Personal and Social Perspectives
As a result of activities in grades 9-12, all students should develop understanding of—
Personal and community health

- Population growth
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

NSES Content Standard G: History and Nature of Science
As a result of activities in grades 9-12, all students should develop understanding of—

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Principles and Standards for School Mathematics

***PSSM* Number Operations Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- understand numbers, ways of representing numbers, relationships among numbers, and number systems;
- understand meanings of operations and how they relate to one another;
- compute fluently and make reasonable estimates.

***PSSM* Algebra Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- understand patterns, relations, and functions;
- represent and analyze mathematical situations and structures using algebraic symbols; use mathematical models to represent and understand quantitative relationships;
- analyze change in various contexts.

***PSSM* Geometry Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships;
- specify locations and describe spatial relationships using coordinate geometry and other representational systems;

- apply transformations and use symmetry to analyze mathematical situations;
- use visualization, spatial reasoning, and geometric modeling to solve problems.

***PSSM* Measurement Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- understand measurable attributes of objects and the units, systems, and processes of measurement;
- apply appropriate techniques, tools, and formulas to determine measurements.

***PSSM* Data Analysis and Probability Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them;
- select and use appropriate statistical methods to analyze data;
- develop and evaluate inferences and predictions that are based on data;
- understand and apply basic concepts of probability.

***PSSM* Problem Solving Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- build new mathematical knowledge through problem solving;
- solve problems that arise in mathematics and in other contexts;
- apply and adapt a variety of appropriate strategies to solve problems;
- monitor and reflect on the process of mathematical problem solving.

***PSSM* Reasoning and Proof Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- recognize reasoning and proof as fundamental aspects of mathematics;
- make and investigate mathematical conjectures;
- develop and evaluate mathematical arguments and proofs;
- select and use various types of reasoning and methods of proof.

***PSSM* Communication Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- organize and consolidate their mathematical thinking through communication;
- communicate their mathematical thinking coherently and clearly to peers, teachers, and others;
- analyze and evaluate the mathematical thinking and strategies of others;
- use the language of mathematics to express mathematical ideas precisely.

***PSSM* Connections Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- recognize and use connections among mathematical ideas;

- understand how mathematical ideas interconnect and build on one another to produce a coherent whole;
- recognize and apply mathematics in contexts outside of mathematics.

***PSSM* Representation Standard:** Instructional programs from pre-kindergarten through grade 12 should enable all students to—

- create and use representations to organize, record, and communicate mathematical ideas;
- select, apply, and translate among mathematical representations to solve problems;
- use representations to model and interpret physical, social, and mathematical phenomena.

Appendix: Detailed Procedures

Step 1 – Completing Initial DOK Level Assignments to All Course Objectives

All objectives in the IED course were assigned to one of four Depth of Knowledge (DOK) levels using the model described above. Detailed procedures for assigning the DOK levels to each objective are discussed in the procedures section of the initial analysis.

Step 2 – Identifying Objectives with an Emphasis on Mathematics and Science

A reviewer familiar with the IED course objectives initially reviewed each objective to identify objectives emphasizing mathematics or science. The *Principles and Standards for School Mathematics* as defined by the National Council of Teachers of Mathematics (NCTM) served as a guide for recognizing mathematic subject matter. The National Science Education Standards as defined by the National Research Council (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/or 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 further 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. Attachment B shows example objectives included in this analysis and the standards to which they were linked.

Step 3 – Conducting Data Compilation and Analysis

Given the original question for this investigation descriptive statistics were chosen as the primary vehicle to analyze the data. First, a series of histograms were created to show how often the four DOK levels occurred throughout course objectives with a mathematics emphasis. Second, a series of histograms were created to show how often the four DOK levels occurred throughout course objectives with a science emphasis. In addition to the histograms other measures of central tendency such as mean, median, mode and standard deviation are provided.

Appendix: Results

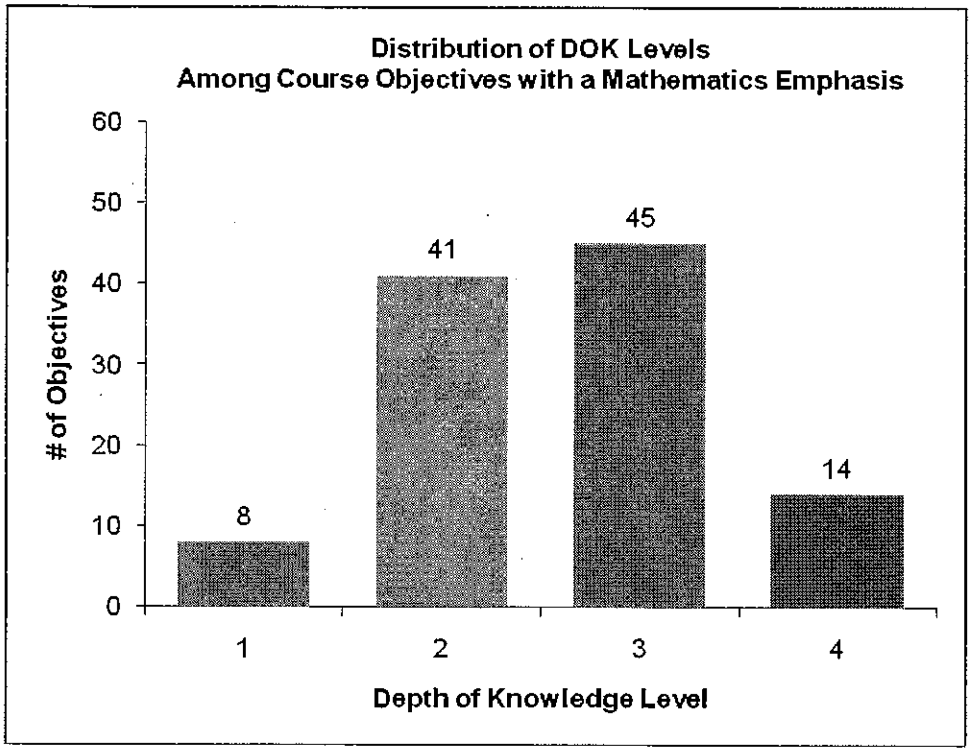
Results Summary

Out of 168 objectives in the IED course 108 (64.28%) were identified for emphasizing one or more of the mathematics standards established by the National Council of Teachers of Mathematics (NCTM). 114 (67.85%) objectives were identified for emphasizing one or more of the stated science standards established by the National Research Council.

The following charts and tables represent the results of the DOK Analysis on the IED course objectives with a mathematics and science emphasis. A summary of general trends and points for discussion is located in the discussion section.

Objectives Emphasizing Mathematics

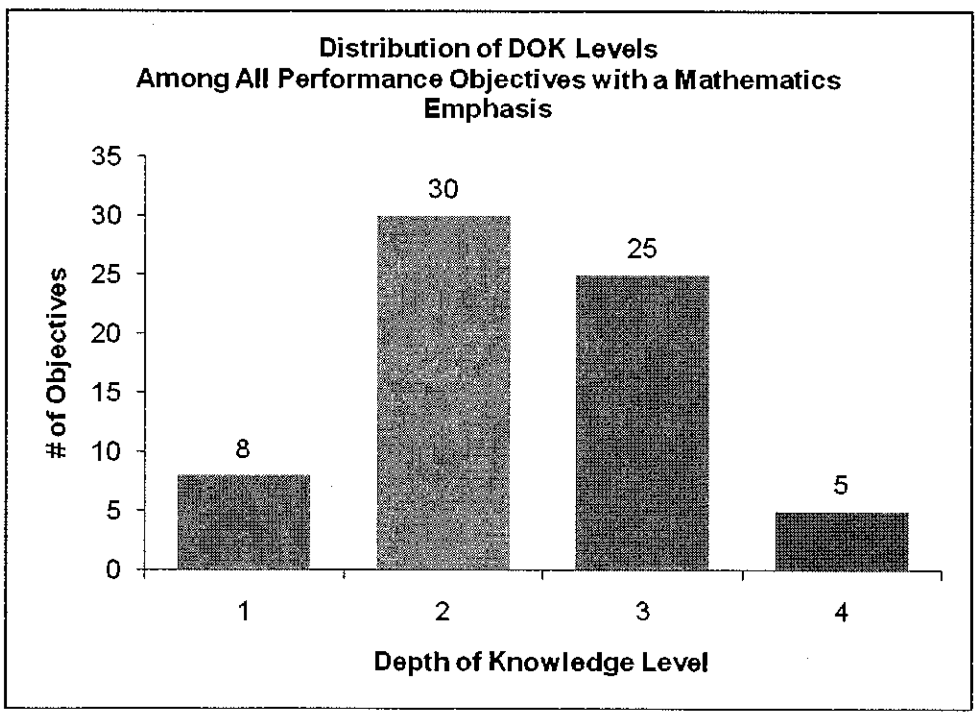
All Course Objectives



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

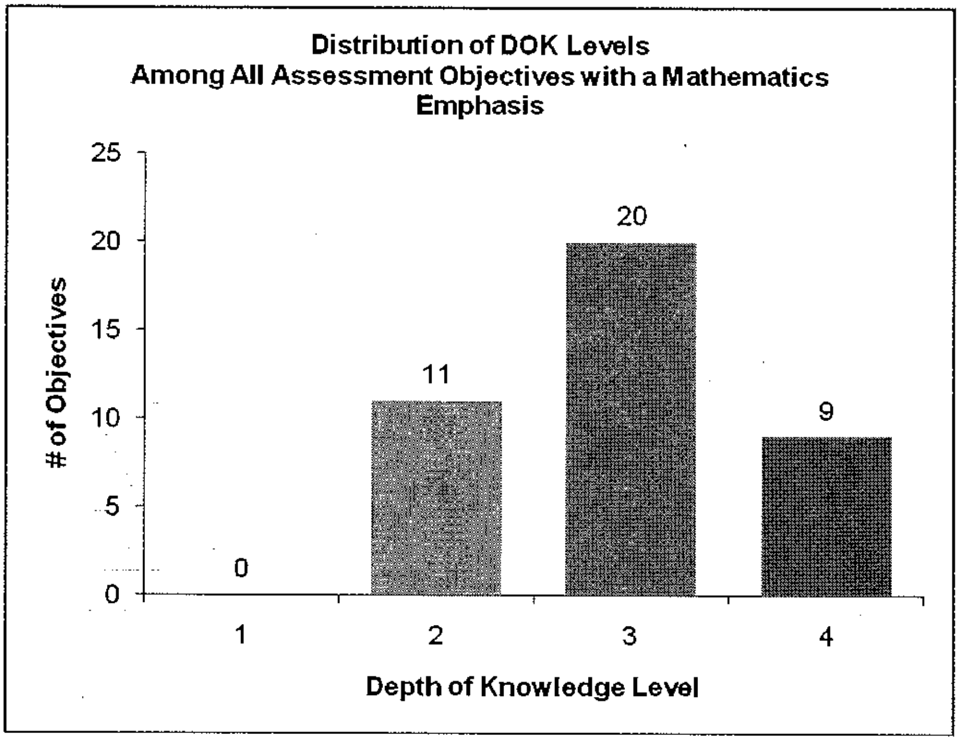
Mean	2.60
Mode	3
Median	3
SD	0.808
Count	108

All Performance Objectives



DOK Level	*Frequency*
1	8
2	30
3	25
4	5

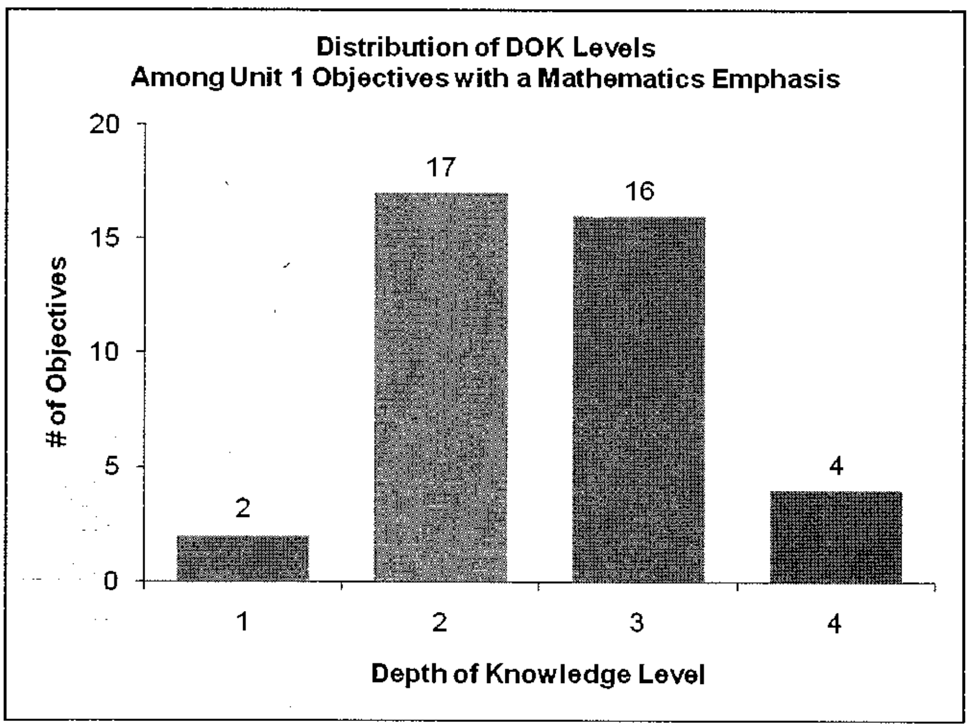
Mean	2.40
Mode	2
Median	2
SD	0.794
Count	68



DOK Level	Frequency
1	0
2	11
3	20
4	9

Mean	2.95
Mode	3
Median	3
SD	0.714
Count	40

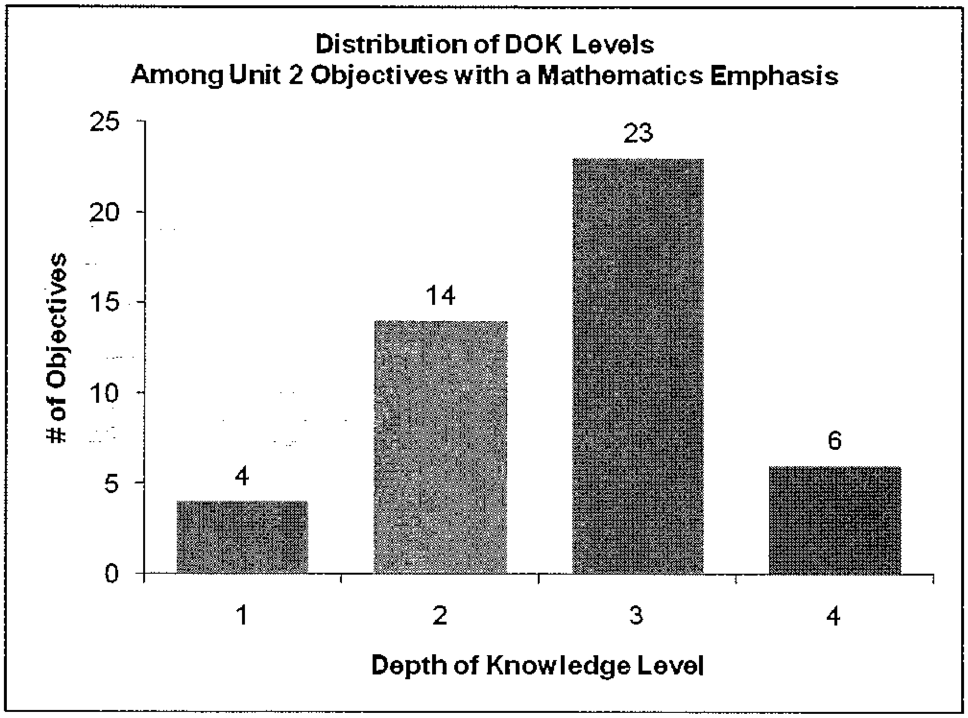
All Unit 1 Objectives



DOK Level	Frequency
1	2
2	17
3	16
4	4

Mean	2.56
Mode	2
Median	3
SD	0.754
Count	39

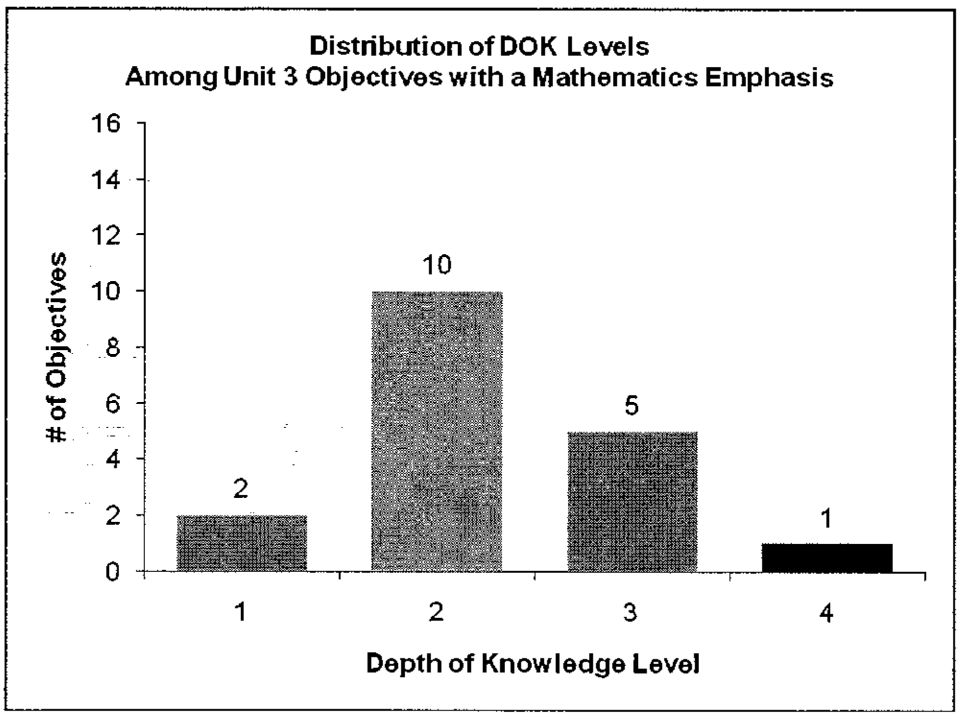
All Unit 2 Objectives



DOK Level	*Frequency*
1	4
2	14
3	23
4	6

Mean	2.66
Mode	3
Median	3
SD	0.815
Count	47

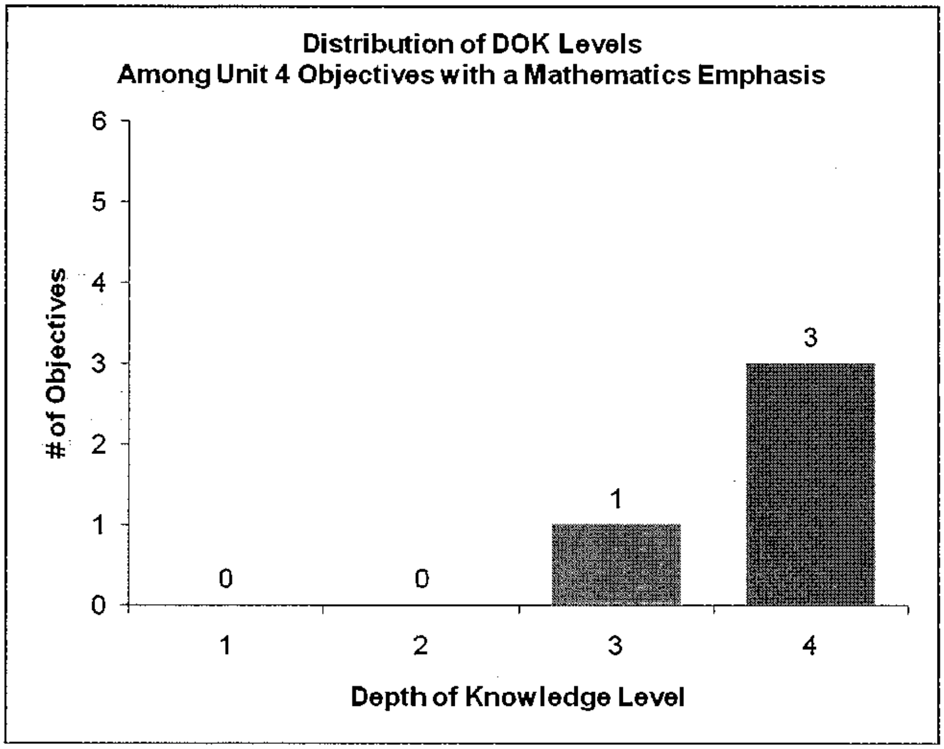
All Unit 3 Objectives



DOK Level	*Frequency*
1	2
2	10
3	5
4	1

Mean	2.28
Mode	2
Median	2
SD	0.752
Count	18

All Unit 4 Objectives

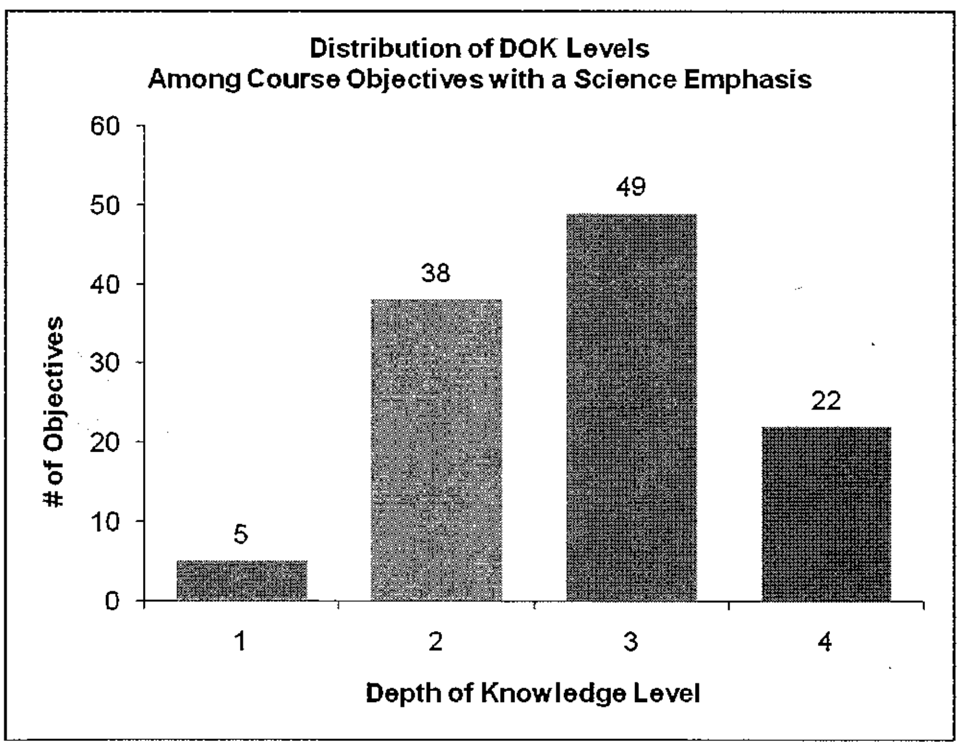


DOK Level	Frequency
1	0
2	0
3	1
4	3

Mean	3.75
Mode	4
Median	4
SD	0.5
Count	4

Objectives Emphasizing Science

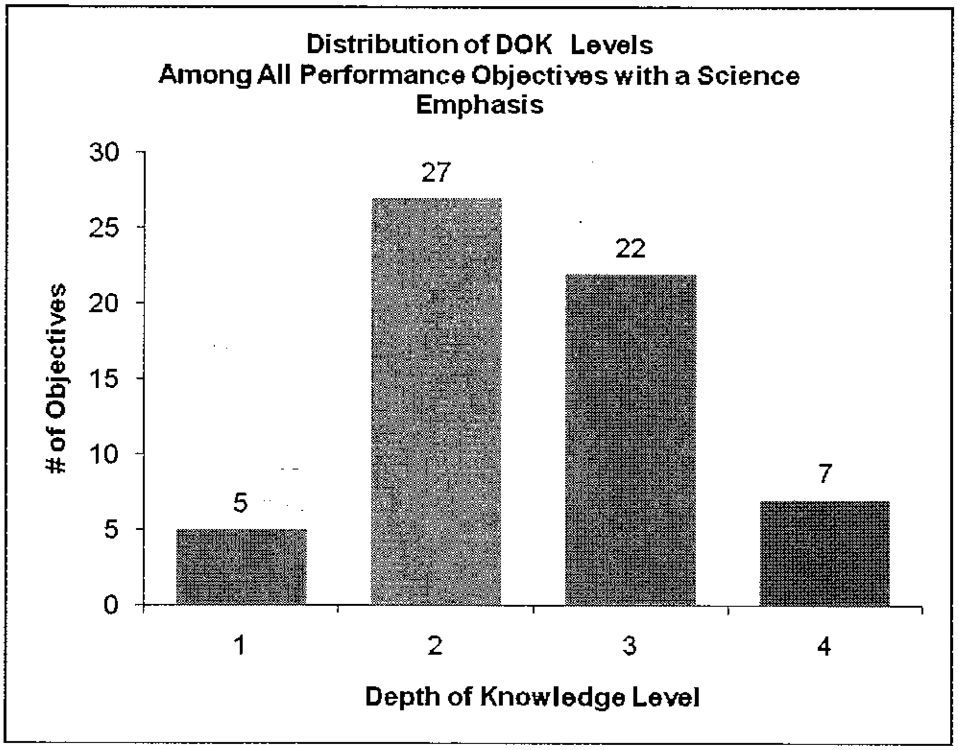
All Course Objectives



DOK Level	Frequency
1	5
2	38
3	49
4	22

Mean	2.77
Mode	3
Median	3
SD	0.810
Count	114

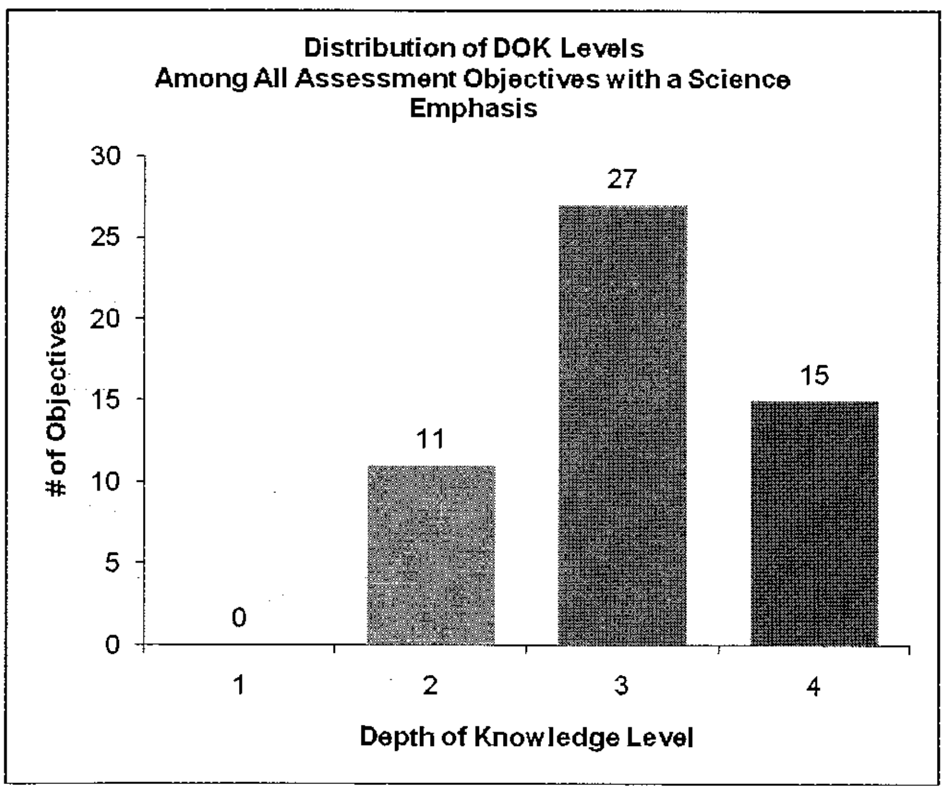
All Performance Objectives



DOK Level	*Frequency*
1	5
2	27
3	22
4	7

Mean	2.51
Mode	2
Median	2
SD	0.809
Count	61

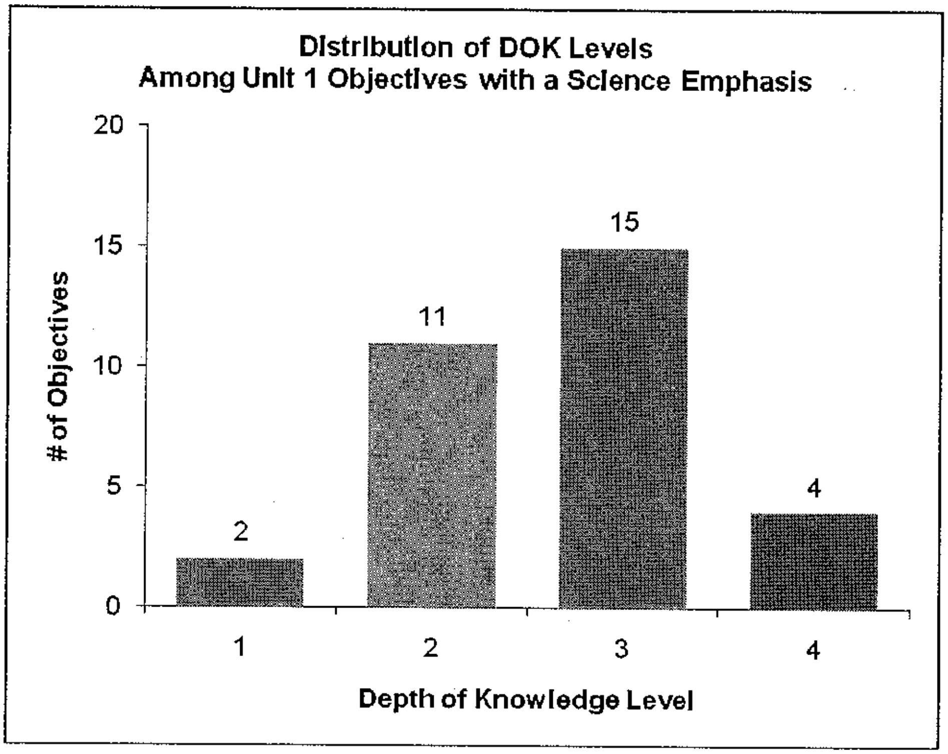
All Assessment Objectives



DOK Level	*Frequency*
1	0
2	11
3	27
4	15

Mean	3.0754717
Mode	3
Median	3
SD	0.70298968
Count	53

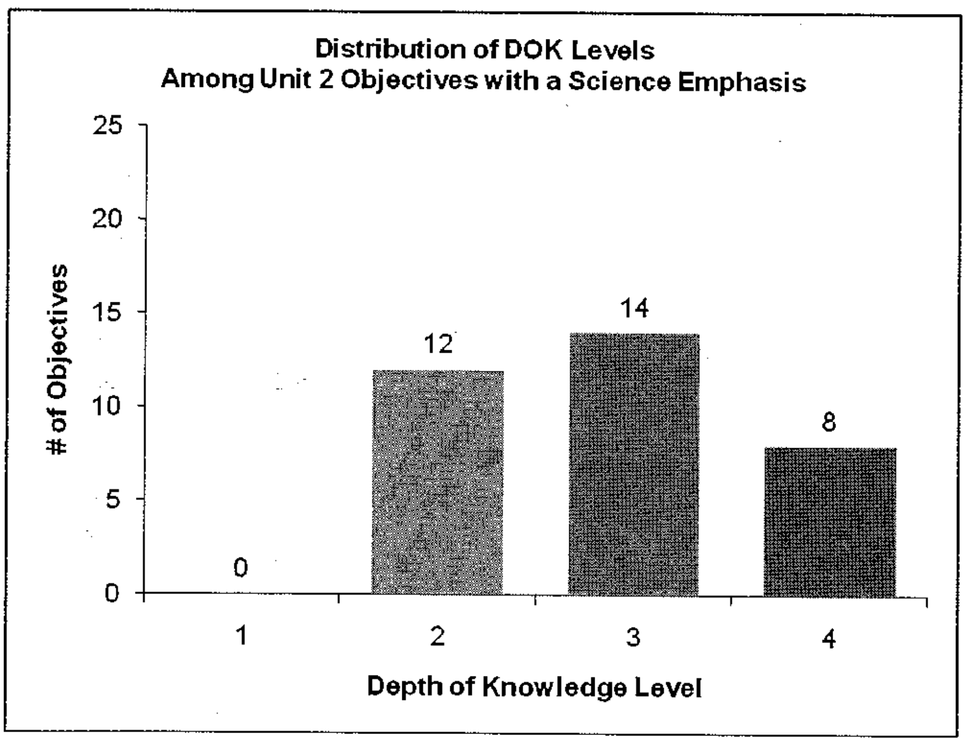
All Unit 1 Objectives



DOK Level	*Frequency*
1	2
2	11
3	15
4	4

Mean	2.66
Mode	3
Median	3
SD	0.787
Count	32

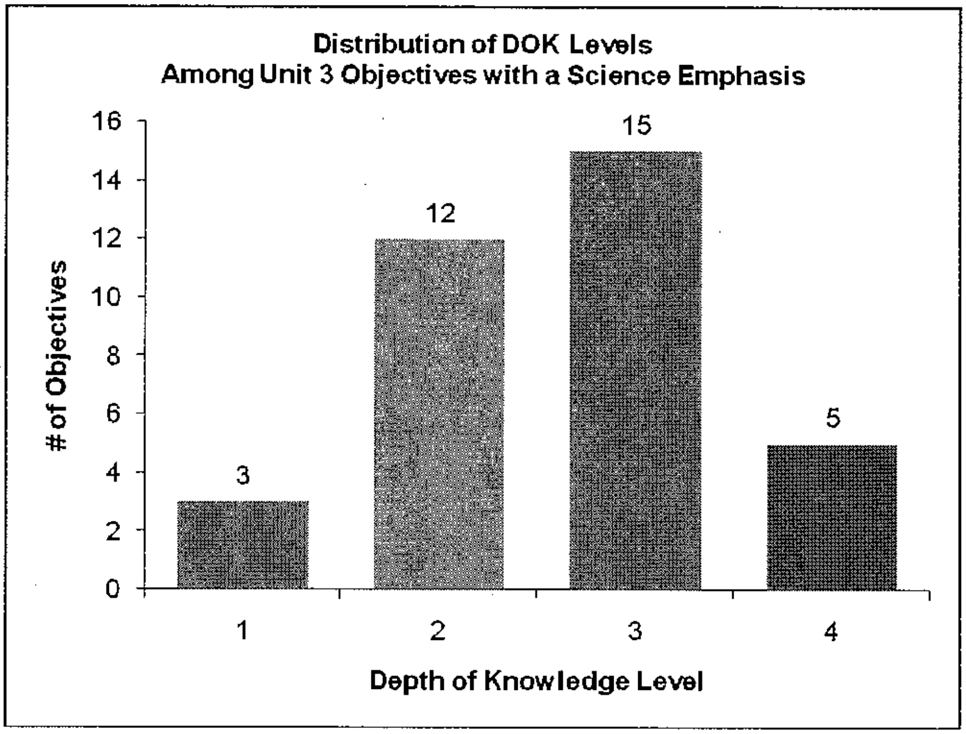
All Unit 2 Objectives



DOK Level	*Frequency*
1	0
2	12
3	14
4	8

Mean	2.88
Mode	3
Median	3
SD	0.769
Count	34

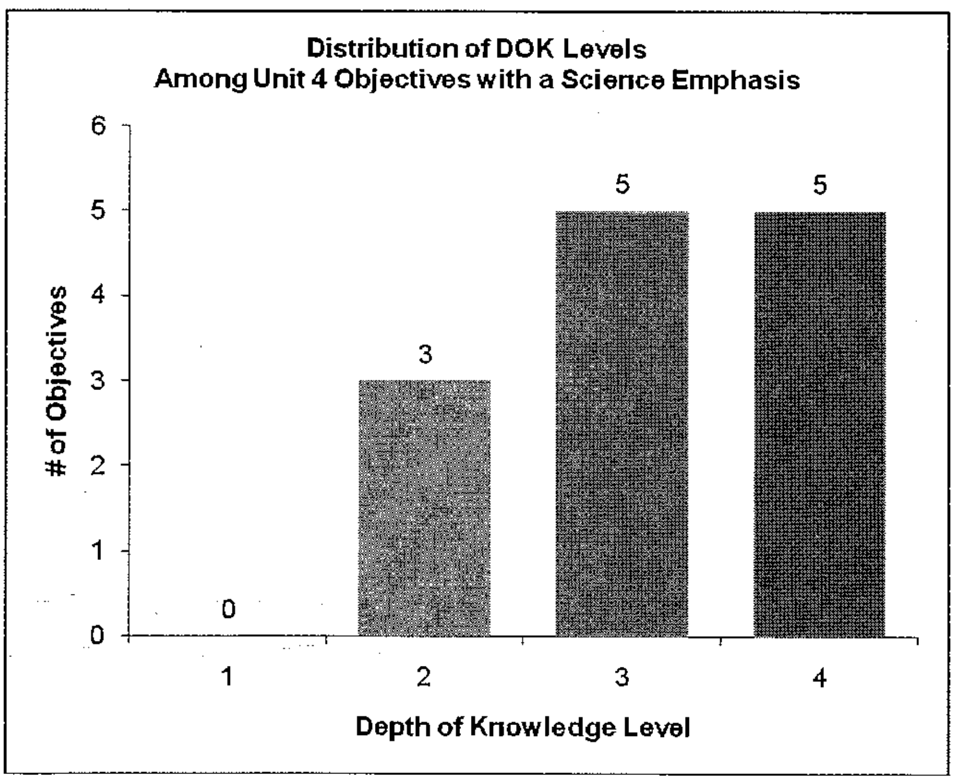
All Unit 3 Objectives



DOK Level	Frequency
1	3
2	12
3	15
4	5

Mean	2.63
Mode	3
Median	3
SD	0.843
Count	35

All Unit 4 Objectives



DOK Level	Frequency
1	0
2	3
3	5
4	5

Mean	3.15
Mode	3
Median	3
SD	0.801
Count	13

Appendix: Discussion

General Observations

The primary question for this investigation was, "What level of cognitive expectation is reflected in the IED course objectives emphasizing mathematics and science knowledge and skill?" The following points reflect some general responses afforded by this analysis:

5) *Generally a large proportion of the objectives in this course were identified for emphasizing content from the mathematics and/or science standards.*
    - 88.69% (149) of the 168 total objectives in the IED course were identified to emphasize either, or both, mathematics and science content standards.
    - 91.39% (85) of the 93 performance objectives in the IED course were identified to emphasize mathematics and/or science content standards.
    - 85.33% (64) of the 75 assessment objectives in the IED course were identified to emphasize mathematics and/or science content standards.

6) *A large proportion of objectives dually emphasized mathematics and science content.*
    - 47.65% (71) of the 167 course objectives included in this analysis demonstrated a dual emphasis on mathematics and science concepts.
    - 50.58% (43) of 85 performance objectives included in this analysis demonstrated a dual emphasis on mathematics and science concepts.
    - 45.31% (29) of 64 assessment objectives included in this analysis demonstrated a dual emphasis on mathematics and science concepts.

7) *Looking across the entire course, generally objectives that emphasize mathematics and science expect the use of short-term strategic thinking (DOK level 3) or employing concepts and skills (DOK level 2).*
    - 42.98% of objectives emphasizing science were assigned to DOK level 3
    - 33.33% of objectives emphasizing science were assigned to DOK level 2
    - 41.67% of objectives emphasizing mathematics were assigned to DOK level 3

- 37.96% of objectives emphasizing mathematics were assigned to DOK level 2

8) *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.*

    - 44.11% of the performance objectives emphasizing mathematics were assigned to level 2, working with skills and concepts. An additional 36.76% of these objectives were assigned to level 3, short-term strategic thinking.
    - 44.26% of the performance objectives emphasizing science were assigned to level 2, working with skills and concepts. An additional 36.06% of these objectives were assigned to level 3, short-term strategic thinking.
    - 50% of the assessment objectives emphasizing mathematics were assigned to level 3, short-term strategic thinking. An additional 22.5% of these objectives were assigned to level 4, extended strategic thinking.
    - 50.94% of the assessment objectives emphasizing science were assigned to level 3, short-term strategic thinking. An additional 28.3% of these objectives were assigned to level 4, extended strategic thinking.

9) *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 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.*

    - 83.10% of objectives emphasizing mathematics and/or science in Unit 1 were written at level 2, working with concepts or skills, or level 3, short-term strategic thinking.

- 77.78% of objectives emphasizing mathematics and/or science in Unit 2 were written at level 2, working with concepts or skills, or level 3, short-term strategic thinking.

- 79.25% of objectives emphasizing mathematics and/or science in Unit 3 were written at level 2, working with concepts or skills, or level 3, short-term strategic thinking.

- 82.35% of objectives emphasizing mathematics and/or science in Unit 4 were written at level 3, short-term strategic thinking, or level 4, extended strategic thinking.

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Attachment A

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

Attachment B

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*