# The Wave Concept Inventory - A Cognitive Instrument Based on Bloom's Taxonomy

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***Abstract*** *- The Foundation Coalition at Arizona State University has developed a new instrument to measure the cognitive development of electrical engineering students in the area of wave phenomena. Originally, the objective was to measure the difference between a novel upper division course offering which integrated an introduction to the properties of electronic materials and the first course for Electrical Engineering majors in electromagnetic engineering. The instrument consists of 20 multiple choice questions with multiple correct answers in many of the situations presented. In fact, choosing more than one correct answer correlates with an increased understanding of the material. The knowledge of the multiple correct answers has been tied to the levels of learning as presented by Bloom's Taxonomy of Educational Objectives. That is, a student that has a higher level of understanding of a particular concept is more likely to correctly choose the multiple correct answers. However, students choosing a higher level answer before a lower level answer is not likely to understand the concept at the higher level. In other words, the student may be guessing. This paper describes how the questions are tied to the levels of learning and presents a discussion of the focus group conducted on the instrument in order to verify the wording of the instrument.*

*(Research supported by NSF funded Foundation Coalition)*

## Introduction

Wave concepts are taught to students in their first Physics courses either in high school or college as well as in electronic materials courses. Students are introduced to quantum mechanics and Schrödinger's wave equation. They discover that the objects that dominate solid state physics, such as the electron, the photon, the phonon, and so on, have wave character. Electrical engineering courses then build upon basic wave concepts to understand analytical models that describe waves, their propagation, and their interactions. For example the students learn Maxwell's wave equations and their application to the propagation of EM waves.

An assessment tool, the Wave Concept Inventory (WCI), was written by R. Roedel and S. El-Ghazaly to assess students' understanding of wave phenomena that begins with basic knowledge from Physics and builds to the graduate level of electrical engineering. The original impetus to writing this instrument was the integration of two courses at Arizona State University (ASU) in the Electrical Engineering Department. Just as integration at the lower division reinforces the connections among courses of various disciplines, integration both within and across the EE curriculum creates a more meaningful experience for the students [1]. Based on the success of this first integration, the EE department is now revamping its curriculum to include multiple sets of integrated courses. The format of this instrument was based on the model developed by Dave Hestenes and co-workers at ASU known as the Force Concept Inventory [2].

The WCI consists of 20 multiple choice questions with multiple correct answers in many of the situations presented. In fact, choosing more than one correct answer correlates with an increased understanding of the material. By increased understanding, we mean that a student is performing at a higher level of learning as demonstrated in the Cognitive domain of learning proposed by Bloom [3]. This paper strives to illustrate the link of each question to Bloom's Taxonomy of Educational Objectives and how choosing multiple correct answers indicates higher levels of learning. That is, a student that has a higher level of understanding of a particular concept is more likely to correctly choose the multiple correct answers. However, students choosing a higher level answer before a lower level answer are not likely to understand the concept at the higher level. In other words, the student may be guessing.

We will classify each question with its corresponding correct answer(s) within Bloom's Taxonomy and then provide results of a focus group session conducted with actual students who had participated in the initial offering of the instrument to support our conclusions.

## Bloom's Taxonomy of Educational Objectives – Cognitive Domain

Bloom's Taxonomy of Educational Objectives in the Cognitive Domain is an attempt to order the cognitive level of a learner and provide a common vocabulary for educators to discuss their students abilities as well as the educator's own personal goals for the student. The structure of Bloom's Taxonomy is hierarchical in nature and provides 6 levels of learning; Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Traditionally these objectives form a hierarchy where the lower levels are seen as prerequisites to gain the upper levels. Many undergraduate courses are taught in the first three or the lower levels of Bloom's Taxonomy; Knowledge, Comprehension, and Application. As evidenced in the new student outcomes defined by ABET 2000 Criteria 2, A through K, engineering education is becoming more interested in the upper levels of thinking skills defined in Bloom's Taxonomy. Table 1 is a presentation of the taxonomy that includes each of the levels as well as some sample verbs and a definition of each level.

Some educators feel that Bloom's Taxonomy must be stepped through, as if the students are stepping their way up the ladder of knowledge. Admittedly, this takes time and perhaps more time than is available in a single semester. However, this hierarchical nature of the taxonomy has been debated. Rhoads, et al present a discussion with supporting data of the ability to use the higher levels of learning to teach the lower levels [4]. A comparison is made of students only taught at the lower levels and students who were taught with all of the levels of learning. What was found is that the students taught at all levels performed equally at the lower levels as the students who were only taught at the lower levels. However, only the students taught at the higher levels could perform at these higher levels. Therefore, students were not hurt by taking them further up the levels, in fact, they could perform just as well at the lower levels. This type of research supports the idea that educators can take students to the top of the taxonomy in the limited time span of a semester without compromising the amount of knowledge learned at the lower levels.

## Wave Concept Inventory

Eight of the questions on the Wave Concept Inventory have multiple answers. These questions and the classification of each of these answers by Bloom's Taxonomy are included in Table 2 and the questions themselves are included in the Appendix. The questions on this assessment instrument range from the lowest level of Bloom's, Knowledge, to the 4$^{th}$ level of Bloom's, Analysis. With the exceptions of questions 6 and 11, the multiple answers actually step their way up the levels of learning. For example, question 4, many students will quickly recognize (a) as the obvious answer since it is Maxwell's equation, therefore, the knowledge level of learning. However, students with more experience will also notice that (b) is a correct answer since it is a generalization of the equation and (c) is a correct answer too since it is a modification or interpretation of Schrödinger's wave equation. Similarly, in question 7, answer (d) is normally the first choice and is considered to be at the comprehension level since it is a translation. The added choice of answer (a) shows deeper understanding of the phenomenon in that it requires a computation and is therefore classified as an application level of learning.

***Table 1 - Bloom's Taxonomy of Cognitive Learning [3]***

| Level | Sample Illustrative Verbs | Definition |
|---|---|---|
| Knowledge | Define, describe, identify, match, memorize, name, order, recognize, recall | Memorize information presented |
| Comprehension | Classify, convert, distinguish, estimate, express, extend, generalize, give examples, infer, predict, recognize, rewrite, restate, translate | Able to restate in own words |
| Application | Apply, change, choose, compute, discover, employ, interpret, manipulate, modify, operate, relate, schedule, show, solve, use, write | Applying knowledge to different or new situations |
| Analysis | Analyze, break down, calculate, categorize, compare, contrast, criticize, differentiate, examine, experiment, identify, infer, model, question, relate, select, separate, subdivide, test | Breaking a large problem into its smaller components and noting relationships |
| Synthesis | Arrange, assemble, collect, combine, construct, create, design, develop, devise, formulate, generate, integrate, manage, organize, plan, propose, rearrange, reconstruct, relate, reorganize, revise, set up, summarize, synthesize, tell, write | Rearranging component ideas into a new whole |
| Evaluation | Appraise, argue, assess, choose, compare, conclude, contrast, defend, discriminate, estimate, evaluate, explain, judge, justify, interpret, relate, predict, rate, select, summarize, support, value | Making decisions based on the whole situation |

***Table 2 - Organization of multiple answer WCI questions in Bloom's Taxonomy***

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|---|---|---|---|---|---|---|
| | | | | | | |
| | (a) Comprehension | (b) Application | | Recognition; Restatement | Computation; Manipulation | |
| | (a) Knowledge | (b) Comprehension | (c) Application | Definition | Generalization | Modification; Interpretation |
| | (b) Knowledge | (c) Comprehension | | Definition | Recognition; Restatement | |
| | (b) Application | (c) Application | | Computation | Illustration | |
| | (d) Comprehension | (a) Application | | Translation | Computation | |
| | (a) Comprehension | (b) Comprehension | (c) Comprehension | Generalization | Generalization | Generalization |
| | (b) Knowledge | (c) Comprehension | (d) Comprehension | Recall | Recognition | Restatement |
| | (a) Comprehension | (b) Application | (c) Analysis | Recognition | Interpretation | Discrimination; Relation |

## Confirmation

A focus group was held with 7 students who had just completed either one course or a two course combination where wave phenomena was a major thread. In these two different types of presentations of wave phenomena, the WCI was used as an assessment instrument of the teaching styles and course format. Therefore, all 7 of these students had taken the inventory twice (pre and post applications were utilized) the semester proceeding the focus group. Though all of the focus group participants remembered taking the inventory, scores were provided upon request after the focus group session on an individual basis. Upon conclusion of the focus group, a brief presentation of the results from the prior semester's application of the instrument was done to inform the students of the results obtained. For an in-depth discussion of these results, see Roedel, et al [5]. There were 58 students who took both the pre and post WCI the prior semester. A sample was called and invited to lunch at a central location on campus based on the student's net gain from pre to post testing. Pizza and cookies were served to all students. Eighteen students were invited to participate in the focus group, of which 7 attended. Multiple schedules were consulted to set the time of the group in order to maximize the number of participants with no scheduled class conflict. Of the 7, 6 males and 1 female participated. The gains exhibited on the instrument from these focus group participants ranged from –1 to 4. This compares to a range of –6 to 8 of the total group of students.

The focus group was moderated by the authors of this paper with 2 additional persons taking notes of the conversations. These persons were a research assistant to the first author and the Director of Assessment & Evaluation for the College of Engineering at Arizona

State University. The format of the focus group was approved by the Office of Human Subjects. All participants signed a statement of understanding that their participation was consent that the outcomes of the study could be used in a research project.

The objective of the focus group was to listen to students discuss how they arrived at the answers they chose and where they felt they obtained the ability to answer the questions. All participants were given a copy of the inventory and the questions were reviewed one by one. Time was given for each participant to read the question and decide what s/he thought the answer was. The moderator then asked the group to discuss what they felt was the correct answer until consensus was reached. The answers were either confirmed as correct or the correct answer(s) were given. The moderator then asked the question of where did the students feel that knowledge was obtained? Efforts were made to include all students in the discussion.

It was found that most of the students had obtained their Knowledge skills from previous Physics courses. However, their higher levels of learning, such as Application and Analysis were learned as a result of their current coursework. Other findings of the focus group included a correction of one question's answers and a clarification of the wording of another question. Also, 2 of the students did not recall being instructed that multiple answers were a possibility. Therefore, the instrument instructions were changed from common verbal instructions from the instructor to written instructions on the instrument, which highlight this point.

## Conclusions

By utilizing multiple correct answers in the same instrument, we were able to address the levels of learning that were achieved at a particular level of coursework and through specific styles of course delivery. It has been demonstrated that students who are taught in a cooperative learning, integrated subject environment perform significantly better than students who are taught in the traditional environment.[5] A focus group was conducted to further define an instrument that can differentiate if students are learning at higher levels of learning and to discuss where these abilities are being obtained.

## Acknowledgements

The Foundation Coalition is an Engineering Education Coalition sponsored by the National Science Foundation through the Texas Engineering Experiment Station, award number 430043 CN. The partner schools in the Foundation Coalition are Arizona State University, Rose-Hulman Institute of Technology, Texas A&M at College Station, Texas A&M at Kingsville, University of Alabama, University of Massachusetts at Dartmouth, and University of Wisconsin at Madison. The authors wish to thank Larry G. Richards for his review that greatly enhanced the overall paper.

## References

[1] R. J. Roedel, S. El-Ghazaly, and J. T. Aberle, " An integrated upper division course in electronic materials and electromagnetic engineering – "wave phenomena" for EEs," Frontiers in Education (FIE) Conference, November, 1998, Tempe, AZ.

[2] D. Hestenes, M. Wells, and G. Swackhamer, "Force Concept Inventory," The Physics Teacher, 30, 141 (1992).

[3] Benjamin S. Bloom, editor, Taxonomy of Educational Objectives, Book 1 Cognitive Domain, Longman, New York, 1956.

[4] Teri Reed Rhoads, Norma Faris Hubele, Terri Fernandez-Parker, Dwayne A. Rollier, "Combining Collaborative, Traditional and Computer-Aided Learning In an Introductory Engineering Probability and Statistics Course," American Society for Engineering Education Pacific Southwest Section 1996 Conference *Proceedings*, pp. 171-182.

[5] R. J. Roedel, S. El-Ghazaly, Teri Reed Rhoads, and E. El-Sharawy, "The Wave Concepts Inventory – An Assessment Tool for Courses in Electromagnetic Engineering, " Frontiers in Education (FIE) Conference, November, 1998, Tempe, AZ.

**Appendix**
**Questions with multiple answers from the Wave Concepts Inventory Survey**

(2) When white light passes through a glass prism, the exiting light is dispersed into a beam of several colors. This is because:
- (a) The angle of refraction at a glass/air interface depends on the wavelength.
- (b) Each component of white light propagates with a different speed through the glass.
- (c) Light actually propagates in curved paths in solid materials, and the curvature is dependent on the wavelength.
- (d) Impurities in the glass absorb the white light and re-radiate the energy in a variety of wavelengths.

(4) Mathematical modeling of wave phenomena involves the solution of a so-called wave equation. Which of the following, if any, linear partial differential

equations can be used to model wave propagation: (Y,K,P constants; x,t location and ttime; u amplitude)

(a) $$\frac{\partial^2 u}{\partial x^2} = K^2 \frac{\partial^2 u}{\partial t^2}$$

(b) $$\frac{\partial^2 u}{\partial x^2} = Y^2 \frac{\partial u}{\partial t} + K^2 \frac{\partial^2 u}{\partial t^2}$$

(c) $$\frac{\partial^2 u}{\partial x^2} = Y^2 \frac{\partial u}{\partial t}$$

(d) $$\frac{\partial u}{\partial x} = P^2 \frac{\partial u}{\partial t}$$

(5) Suppose two different sound waves encounter each other - they meet at the same location in space at the same time. What happens?

(a) They scatter from each other and move in divergent directions.
(b) Their amplitudes add together.
(c) Their displacements add together.
(d) Their phases add together.

(6) A medium in which waves are propagating is said to be dispersive when:

(a) The waves have the same group velocity and phase velocity
(b) The propagation frequency is a non-linear function of the propagation constant (wave number)
(c) The medium is vacuum
(d) Longitudinal waves propagate with a velocity different from transverse waves

(7) In many physical systems, waves known as standing waves can appear. They are called standing waves because:

(a) They are the superposition of traveling waves
(b) They have zero phase velocity
(c) They propagate with zero dispersion
(d) They have zero group velocity

(11) Waves passing through the earth are called seismic waves. Seismic waves are:

(a) Transverse waves
(b) Longitudinal waves
(c) Waves that exhibit polarization
(d) Waves that exist only on the surface of the earth

(12) If electromagnetic waves can be generated by accelerating or decelerating charges, then when masses are accelerated:

(a) Thermal waves are produced
(b) Sound waves are produced
(c) Gravitational waves are produced
(d) Electromagnetic waves are produced

(14) When a guitar string is plucked, a sound wave is produced. This sound wave has a spectrum that consists of “fundamental” and “harmonic” frequencies, because:

(a) The waves on the string are confined to a limited region
(b) Only certain frequencies are allowed because of interference
(c) The plucking forces the motion of the string into the observed spectrum
(d) This minimizes the potential energy in the system