

# The Wave Concepts Inventory – An Assessment Tool for Courses in Electromagnetic Engineering

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**Abstract** – *The Foundation Coalition at Arizona State University offered for the first time a novel upper division integrated course in Electrical Engineering in the fall '97 semester. The courses involved were (1) an introduction to the properties of electronic materials and (2) the first course for EE majors in electromagnetic engineering. The main thread that integrated the two courses was “wave phenomena.” To determine whether this integration successfully teaches the students in wave phenomena, we developed an assessment tool, which we have called the Wave Concepts Inventory. This paper will describe in detail the organization of the Waves Concepts Inventory and its use in assessing upper division students in their understanding of wave concepts.*

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## Introduction

The Department of Electrical Engineering at Arizona State University has started the process of developing an upper division curriculum that would be a natural extension of the Foundation Coalition lower division classes that are presently in place. Coursework that meets the Foundation Coalition goals follow the following design rules: [1-4]

1. The coursework must be integrated.
2. There must be significant technology infusion.
3. Active learning strategies must be employed.
4. Assessment of the coursework must take place.

During the fall 1997 semester, we offered through the Electrical Engineering Department at Arizona State University (ASU) a new upper level Foundation Coalition course, which combines and integrates two other courses – introduction to the properties of electronic materials (ECE352) and the first course in electromagnetic engineering (EEE340) [5]. The main thread that integrates the two

courses is “wave phenomena.” In the electronic materials portion of the class, the students are introduced to quantum mechanics and Schrödinger’s wave equation. Here they discover that the objects that dominate solid state physics, such as the electron, the photon, the phonon, and so on, have wave character. And of course, in the electromagnetic portion, the students learn Maxwell’s wave equations and their application to the propagation of EM waves.

What strengthens this integrated offering is that students see at one time several analytical models that describe waves, their propagation, and their interactions. But to determine whether this integration successfully teaches the students in wave phenomena, we developed an assessment tool, which we have called the Wave Concepts Inventory (WCI). This WCI survey is based on the model developed by Dave Hestenes and co-workers at ASU known as the Force Concept Inventory [6]. The FCI has been assembled and refined over several years to test freshman students on their intuition concerning kinematics concepts, Newton’s Laws, and conservation principles.

The WCI is a multiple-choice examination, but allows for more than one correct choice in most of the questions. In fact, choosing more than one answer correlates with increasing understanding of the material. The test was administered before and after the new course - and to a group of similar electrical engineering students taking the traditional E&M course as a comparison group. This paper will describe in detail the organization of the Wave Concepts Inventory and its use in assessing all upper division students in their understanding of wave phenomena.

## The Wave Concepts Inventory

The WCI consists of 20 multiple choice questions with possible 34 correct answers. Ten of the twenty questions are shown in Appendix 1. The survey asks a variety of questions that probe several areas of knowledge, including visualization of waves, mathematical depiction of waves, and

wave definitions. Though the WCI is a multiple-choice examination, it allows for more than one correct choice in most of the questions. In fact, choosing more than one answer correlates with increasing understanding of the material. For example, in question 4, many students will quickly recognize (a) as the obvious answer since it is Maxwell's Equation, but students with more experience will also notice that (c) is a correct answer too since it is a version of Schrödinger's wave equation. Similarly, in question 7, answer (d) is normally the first choice, but the added choice of answer (a) shows deeper understanding of the phenomenon.

### Analysis of the results

There are multiple correct answers to individual questions and credit was given to individuals who chose more than one correct answer. No penalty was imposed for incorrect answers, and therefore, guessing was not discouraged. The test was administered to two classes of electrical engineering students. The first class was the traditional class that had 58 students completing the semester. There were 11 juniors (19%), 40 seniors (69%), 6 graduate students (10%), and 1 unclassified undergraduate (2%) in this class. The comparison class was what we refer to as the integrated class. This class was composed of 22 students. There were 8 juniors (36%), 13 seniors (59%), and 1 graduate student (5%). The scoring of the two classes was a comparison of the number of total correct answers from the test being taken at the beginning of the semester (Pre-test) and the same test being taken at the end of the semester (Post-test). Perhaps more importantly is the change that was affected in the individual students. This statistic is reflected in the "Change" variable which represents the post-test score minus the pre-test score for those students who took both tests. Table 1 is a summary of the descriptive statistics associated with each variable.

Tests on the changes in each student from the pre- to the post-semester tests were performed on the means and standard deviations. Each class was used to test the null hypothesis that the mean change (post-test minus pre-test)

was equal to zero versus the alternative that the mean change is greater than zero. By formulating the hypothesis in this manner, we are hoping to make the strong conclusion and reject the null hypothesis, in favor of seeing a larger increase in the post-test scores. For the traditional class, we failed to reject this hypothesis (p-value = 0.077). That is, on the average, there is not a significantly positive change in test scores from the beginning to the end of the semester.

Table 1 – Descriptive Statistics for Each Course

	Pre-Test	Post-test	Change
<b>Traditional Course</b>			
Average	10.4	11.9	0.9
Median	10	12	1
Standard Deviation	2.8	3.3	3.4
Sample Size	54	51	39
<b>Integrated Course</b>			
Average	11.8	15.2	3.4
Median	12	15	3
Standard Deviation	2.8	2.9	1.5
Sample Size	21	20	19

For the integrated class, the hypothesis was rejected with a p-value of 0.0001 indicating that there was a significant increase in the post-test score. A test of the null hypothesis that the changes between the traditional and integrated courses were equal versus the alternative that the changes were unequal was performed. This null hypothesis was also rejected (p-value = 0.0004). This can be seen graphically in Figure 1. This figure is a dotplot graph of the changes from post to pre-test scores within each course. Another interesting note is that only positive changes resulted in the integrated course. Normality was confirmed for the integrated course due to its small sample size using the Anderson Darling test statistic. [7]

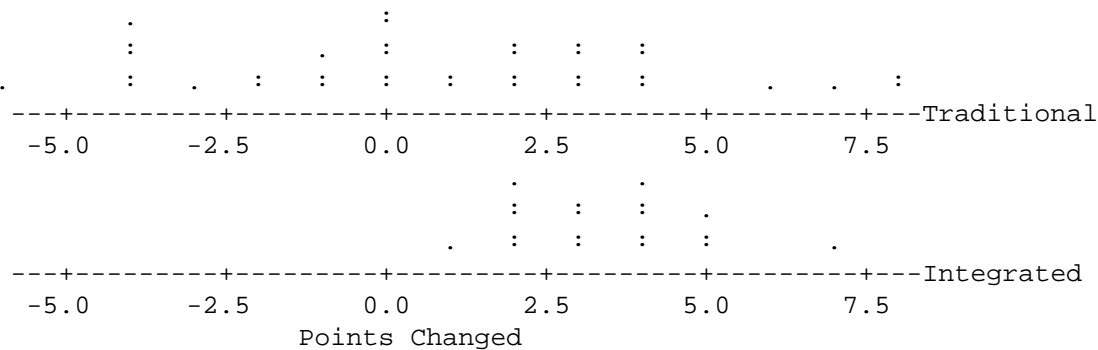


Figure 1 - Character Dotplot Graph of the Net Changes in Test Scores from Pre to Post-test Administration for the Traditional and Integrated Courses.

Table No. 2 – Correlations Between Variables for Each Course

Correlations (p-value)	Grade Received in Course		Pre-test Score		Post-test Score	
	Traditional	Integrated	Traditional	Integrated	Traditional	Integrated
Post-test Score	0.28483 (0.0831)	0.38974 (0.0894)	0.49708 (.0020)	.87386 (.0001)		
Change			-0.45015 (0.0059)		0.551057 (.0015)	

An analysis of the correlations between the pre-test, post-test, changes, and grade received in the course was performed. In both courses, the pre-test scores were negatively correlated with the changes. Therefore, the higher the pre-test score, the lower the change from the pre to the post-test. The grade received in the course was not found to be significantly correlated with any of the other variables. The correlation for the grade received in the course with the post-test score was highest, though not significant, within each of the courses. This value with the other significant correlations found among the variables is included in Table 2.

In the engineering world, correlations in the range of 0.5 are not typically considered significant. In general, correlation coefficients greater than or equal to 0.8 indicate strong linear relationships, while correlation coefficients less than 0.6 indicate weaker relationships. Therefore, only the integrated course pre-test to post-test correlation is in the range of significance for engineers. This correlation is so high due to the fact that only positive changes resulted in the integrated course as was shown in Figure 1.

There are many possible factors that could have created the above differences. Some speculative reasons will be noted here with the understanding that no true cause and effect relationships are investigated. Two faculty members functioning as a team-teach the integrated course. These faculty members are the authors of the instrument used to evaluate the two courses. Though the instrument was written a full semester before its application, the authors will tend to write questions on the concepts that they feel to be most important. These views may or may not be shared with other instructors. Also, teaching to the test may have been a factor. The authors of the instrument made great efforts not to make this a large factor. The test was administered and graded by a disinterested third party. In fact, this third party

did not know which class the instrument authors taught and which was not. All grading and reporting of results took place after the completion of the semester. Additional factors that could have had an effect on the data are the small class size for the integrated course, the small class had 2 instructors, and these students had potentially twice as many lectures since students in the comparison class were not required to take the second course simultaneously.

Future plans for the continued validation of this instrument include the evaluations of personal interviews that were conducted in the spring of 1998 with students who took the test in the fall of 1997. We are currently interviewing faculty who teach the subject matter for their input. Both of these activities are a part of our question by question analysis that is currently underway with the goal of differentiating between good and bad questions as well as good and bad possible solutions to each question. We are interested in having individuals use this instrument in other institutions and situations. Please contact the first author if you are interested in participating in the future research of this instrument. In return for administration of the instrument, we will provide scoring and statistical analysis of the results.

More details about the structure of the Wave Phenomena course can be found on the same webpage that the students themselves used:

<http://www.eas.asu.edu/~roedel/ece352>

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## Appendix 1.

### Sample questions from the Wave Concepts Inventory Survey

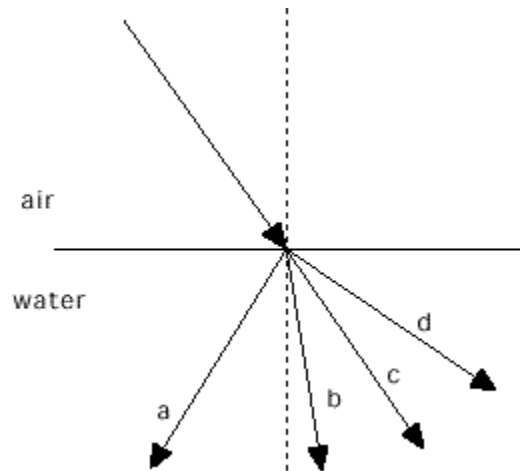
(1) A wave can be defined as:

- a A self-propagating periodic disturbance that transports matter through space and time.
- b A self-propagating non-periodic disturbance that transports matter through space and time.
- c An evanescent periodic disturbance that transports electromagnetic energy through space and time.
- d A self-propagating periodic disturbance that transports energy and momentum through space and time

(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.

(3) A ray of monochromatic light propagating in air strikes the surface of water at an angle as shown



below. Along which path does the ray propagate in the water?

(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 time; 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.

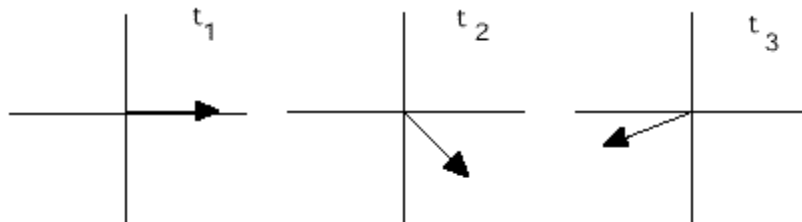
(6) A medium in which waves are propagating is said to be dispersive when:

- 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

(8) With special detection apparatus, you are able to observe the electric field vector of an electromagnetic wave propagating directly toward you. As time advances, the vector has this orientation:



This wave is said to be:

- a Unpolarized.
- b Linearly polarized.
- c Circularly polarized.

d Elliptically polarized.

(9) The x-component of an electromagnetic wave propagating in free space is described by:

$$E_x(x, y, z, t) = E_0 \exp[j(x + y + z - t)]$$

This wave is known as a plane wave because:

- a It is the simplest mathematical description of a propagating wave.
- b The amplitude is constant.
- c The surface of constant phase at any instant of time is planar.
- d The displacement direction is perpendicular to the propagation direction.

(10) Plane waves impinge on a barrier that contains a linear opening (slit). After passing through the slit, the light strikes a screen, and the intensity pattern on the screen looks like:

