

# Concept Inventory Assessment Instruments for Electromagnetics Education

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## 1. Introduction

There is an increasing need for assessment instruments to evaluate pedagogical techniques and curricular reforms in science and engineering. This paper presents the development of an assessment tool designed to measure students' understanding of fundamental concepts in electromagnetics. The tool is termed the Electromagnetics Concept Inventory (EMCI). Although primarily intended for junior-level electromagnetics courses in electrical engineering departments, the EMCI can also be used in a variety of undergraduate and graduate electromagnetics-related courses in engineering and physics departments. The instrument may be used for several different purposes and can be administered in different ways, but the most important purpose is to assess students' performance and evaluate the effectiveness of instruction, usually as the "gain" between the course "pretest" and "posttest" scores. The EMCI Version 1.0 is composed of three exams: EMCI-Fields, EMCI-Waves, and EMCI-Fields & Waves, to allow instructors to target specific knowledge areas. The questions on the exams focus on the core concepts of the material while requiring little or no computation.

The EMCI is motivated by the Force Concept Inventory (FCI), created by Halloun and Hestenes [1-2] and its impact on physics education. The FCI was designed to measure conceptual understanding of Newtonian Mechanics. The questions are posed to focus on intuitive comprehension independent of knowledge of the terminology or numerical modeling. Following the lead of the FCI, faculty members are creating concept inventories for other disciplines [3-6]. More information about the concept of concept inventories can be found in a paper by Evans and Hestenes [7].

## 2. Electromagnetics Concept Inventory

The EMCI-Fields version 1.0 consists of 23 multiple-choice questions on electrostatic, magnetostatic, and time-varying electromagnetic fields. It is designed for a typical first-semester electromagnetics course in a two-semester sequence. The EMCI-Waves, consisting of 23 questions on uniform plane waves, transmission lines, waveguides, and antennas, is intended for a typical second-semester course in the two-semester sequence. The EMCI-Fields & Waves is an integral test with 25 questions on all basic topics in undergraduate electromagnetics. Instructors teaching a one-semester electromagnetics course may either use both the EMCI-F and EMCI-W (at the same time or at different points in the semester) or use the EMCI-F & W only. EE and physics faculty members may also use these exams as review tests in senior and graduate EM-related classes.

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In addition to the copies of the three tests, the EMCI package includes detailed instructions, concept lists, and answer sheets. An instructor feedback form is also provided. It requests input from the instructor regarding the EMCI tests and how well they fit with the objectives, assessment processes, and pedagogical approaches used in the course. In addition, it solicits comments and suggestions for improvement of the instruments.

### 3. EMCI-Fields Concepts

The list below shows the concepts covered by the EMCI-Fields version 1.0. The numbers in parentheses indicate how many questions in the current version of the exam address the outlined topics. Note that the numbers do not add to 23 because questions covering more than one concept are counted multiple times.

- Coulomb's law (1)
- Adding vectors (forces and fields) in space (2)
- Using symmetry (2)
- Gauss' law (1)
- Circulation of the electrostatic field intensity vector along a closed path is zero (1)
- Electrostatic field intensity vector is the gradient of the electric potential (1)
- Distribution of surface charges on a conducting body of complex shape (1)
- A conducting body is equipotential (1)
- Electrostatic induction (2)
- Electrostatic shielding (1)
- Boundary conditions for the electric field intensity vector at a conducting surface (1)
- Image theory (1)
- No field in a conductor (2)
- Capacitance of a capacitor (1)
- Fields in capacitors with inhomogeneous dielectrics; Relationship  $\mathbf{D} = \epsilon\mathbf{E}$  (2)
- Boundary conditions at dielectric-dielectric interfaces (2)
- Current density vector (1)
- Current continuity and boundary conditions for time-invariant currents (1)
- Force on a wire conductor with a time-invariant current in a magnetostatic field (2)
- Magnetic field due to a straight wire conductor with a time-invariant current (1)
- Torque on a current loop in a magnetostatic field (1)
- Ampere's law (1)
- Distribution of a time-invariant current in a cross-section of a conductor (1)
- Law of conservation of magnetic flux (2)
- Magnetic circuit (1)
- Boundary conditions for the magnetostatic field; Relationship  $\mathbf{B} = \mu\mathbf{H}$  (1)
- Curl and divergence (1)
- Definition of field lines (1)

- Electromagnetic induction (Faraday's law) - transformer emf (1)
- Electromagnetic induction - motional emf (1)
- Electromagnetic induction - combination of transformer and motional emf (1)
- Mutual inductance (1)
- Lines of the magnetic field due to a current loop (1)
- Maxwell's equations; Generalized Ampere's law with displacement current added (1)

#### 4. EMCI-Waves Concepts

The following list shows the concepts covered by the EMCI-Waves version 1.0.

- Basic properties of a uniform plane wave propagating in a lossless medium (1)
- Definition of a good conductor/good dielectric (1)
- Wave propagation in a good conductor; Skin depth; Electromagnetic shielding (1)
- Standing waves (4)
- Wave reflection at normal incidence on a perfectly conducting boundary (2)
- Short dipole antenna as a receiving antenna (electric probe) (1)
- Small loop antenna as a receiving antenna (magnetic probe) (1)
- Quarter-wave matching (1)
- Electrical dimensions of an object (1)
- Wave polarization (1)
- Wave transmission (refraction) at oblique incidence on a dielectric boundary (1)
- Energy localization and transfer in a lossless transmission line with a TEM wave (1)
- Transmission line is not a pair of short-circuiting conductors (1)
- Equivalent input impedance and impedance transformation by a transmission line (2)
- Equivalent circuit model of a transmission line (1)
- Modeling of losses in conductors and dielectric of a transmission line (1)
- Smith chart (1)
- Relationship between frequency and wavelength (1)
- Transients on a transmission line (3)
- Velocity of pulse propagation and its dependence on the dielectric permittivity (1)
- Dynamic impedance seen by a generator in the transient analysis of a transmission line (1)
- Reflections at the load and generator in the transient analysis of transmission lines (1)
- Modes in a rectangular waveguide; Dominant mode; Cutoff frequency (2)
- Oscillating of the electric and magnetic energy in a rectangular cavity resonator (1)
- Far-field region of an antenna (2)
- Dependence of the radiation electric field intensity on the distance from a transmitting antenna (1)
- Antenna directivity and directive gain (2)
- Quarter-wave monopole antenna and equivalent half-wave dipole antenna (1)

- Effective area (aperture) of a receiving antenna; Poynting vector (1)
- Friis transmission formula for a radio link (1)

## 5. Conclusions

The Electromagnetics Concept Inventory is a set of assessment instruments designed to measure students' understanding of fundamental concepts in electromagnetics, primarily within junior-level electromagnetic theory courses in electrical engineering departments. The EMCI Version 1.0 has been developed during the 2000-01 academic year and the summer of 2001. The tests are being administered in a pre- and post-test format in the Fall 2001/Spring 2002 Electromagnetic Theory I and II courses at the University of Massachusetts Dartmouth. The tool has been shared with colleagues in other NSF Foundation Coalition institutions and other schools in the USA. Sample questions from the EMCI instruments will be presented and discussed at the AP-S symposium, along with the results of preliminary testing of the inventory on small student populations. Current versions of the EMCI tests will be available at the symposium.

It is impossible to develop a completely effective concept inventory test in a single iteration; many cycles of instrument design, testing, and redesign are necessary to develop a calibrated tool that will yield repeatable results. Consequently, future efforts will be devoted to testing and improving the EMCI exams, and to establishing performance norms.

The author of this paper is seeking faculty interested in participating in this study, not only to administer the tests in their classes, but also to collaborate on the improvement of the instruments and co-author future versions of the EMCI.

## References

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