COURSE-SCALE LEARNING GOALS
E&M II

These learning goals were created by a group of physics faculty from a number of research areas, including physics education research. Rather than addressing specific content to be covered in a course (as with a syllabus), this list of broader learning goals represents what we think students should be able to *do* at this stage of their development as physicists.

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1. **Build on earlier material:** Students should deepen their understanding of introductory electromagnetism, junior-level E&M, and necessary math skills (in particular, vector calculus and differential equations).

2. **Maxwell's equations:** Students should see the various topics in the course as part of a coherent theory of electromagnetism; i.e., as a consequence of Maxwell's equations.

3. **Math/physics connection:** Students should be able to translate a description of a junior-level E&M problem into the mathematical equation(s) necessary to solve it; explain the physical meaning of the final solution, including how this is reflected in its mathematical formulation; and be able to achieve physical insight through the mathematics of a problem.

4. **Visualization:** Students should be able to sketch the physical parameters of a problem (e.g., electric or magnetic fields, and charge distributions). They should be able to use a computer program to graph physical parameters, create animations of time-dependent solutions, and compare analytic solutions with computations. Students should recognize when each of the two methods (by hand or computer) is most appropriate.

5. **Organized knowledge:** Students should be able to articulate the important ideas from each chapter, section, and/or lecture, thus indicating how they have organized their content knowledge. They should be able to filter this knowledge to access the information they'll need to solve a particular physics problem, and make connections between different concepts.

6. **Communication.** Students should be able to justify and explain their thinking and/or approach to a problem or analysis of a physical situation, in either written or oral form. Students should be able to understand and summarize a significant portion of an appropriately difficult scientific paper (e.g. an *AJP* article) on a topic from electromagnetism; and have the necessary reference skills to search for and retrieve a journal article.

7. **Problem-solving techniques:** Students should be able to choose and apply the problem-solving technique that is appropriate for a particular situation (e.g., whether to use the integral or differential forms of Maxwell's equations). They should be able to apply these methods to novel contexts (i.e., solving problems that do not map directly to examples in a textbook), indicating how they understand the essential features of the technique, rather than just the rote mechanics of its application.

   ...7a. Approximations: Students should be able to effectively use approximation techniques, and recognize when they are appropriate (e.g., at points far away or very close to the source). They should be able to decide how many terms of a series expansion must be retained to find a solution of a given order, and be able to complete a Taylor Series to at least two terms.

   ...7b. Symmetries: Students should be able to recognize symmetries, and be able to take advantage of them when choosing the appropriate method of solution (e.g., correctly applying the Maxwell-Ampere law to calculate the magnetic field of an infinitely long wire).

   ...7c. Integration: Students should be able to write down the line, surface or volume integral required for solving a specific problem, and correctly follow through with the integration.

   ...7d. Superposition: Students should recognize that – in a linear system – a general solution can be formed by the superposition of multiple components, and a specific solution found by applying appropriate boundary conditions.

8. **Problem-solving skills:** Students should be able to draw on an organized set of content knowledge (LG#5), and apply problem-solving techniques (LG#7) with that knowledge in order to carry out lengthy analyses of physical situations. They should be able to connect all the pieces of a problem to reach a final solution. They should recognize the value for learning the material of taking wrong turns, be able to recover from their mistakes, and persist in working towards a solution even though they don't necessarily see the path to that solution when they first begin the problem. Students should be able to articulate what it is that needs to be solved for in a given problem, and know when they have found it.

9. **Expecting and checking solutions:** When appropriate for a given problem, students should be able to articulate their expectations for the solution, such as the magnitude or direction of a vector field, the dependence of the solution on coordinate variables, or its behavior at large distances. For all problems, students should be able to justify the reasonableness of a solution (e.g., by checking its symmetry, looking at limiting or special cases, relating to cases with known solutions, dimensional analysis, and/or checking the scale/order of magnitude of the answer).

10. **Derivations/proofs:** Students should recognize the utility and role of formal derivations and proofs in the learning, understanding, and application of physics. They should be able to identify the necessary elements of a formal derivation or proof; and be able to reproduce important ones, including an articulation of their logical progression. They should have some facility in recognizing the range/limitations of a result based on the assumptions made in its derivation.

11. **Intellectual maturity:** Students should accept responsibility for their own learning. They should be aware of what they do and don't understand about physical phenomena and classes of problems, be able to articulate where they are experiencing difficulty, and take action to move beyond that difficulty (e.g., by asking thoughtful, specific questions).