$$v = \sqrt{2gh} \quad (1)$$

where g is the acceleration due to gravity. As the magnet passes through the coil D of width d , an EMF is induced with a peak value e which may be written in the form

$$e \propto \frac{\text{change in flux}}{\text{time}} \propto \frac{NAH}{\Delta t} \quad (2)$$

where N is the number of turns in the coil D , A is the effective cross-sectional area of D , H is the magnetic field strength, and Δt is the average time during which magnetic flux changes from a zero value to maximum. The time Δt is obviously proportional to d/v and hence, (2) reduces to

$$e = K \cdot \left(\frac{NAH}{d} \right) \cdot v \quad (3)$$

where K is a factor which accounts for the uncertainty in magnetic field configuration near the coil D of width d . Equation (3) shows that the peak value of the induced EMF in coil D is directly proportional to the velocity of the magnet at the coil D .

IV. PERFORMANCE

In order to test the validity of (3) and, hence, Faraday's laws of electromagnetic induction, the magnet is released from different heights in succession and corresponding induced voltages e are recorded. v is computed from (1) and then e is plotted against v . Experimentally, this plot was found to be a straight line demonstrating the validity of (3). Note that for each setting of h , charges on C_1 and C_2 are to be cleared using manually operated ON/OFF switch SW and the magnet is allowed to fall 3–4 times to get good results.

V. CONCLUSIONS

A novel apparatus is described to study Faraday's laws of electromagnetic induction using falling body formulas. The approach is straightforward, illustrative, and does not require the use of expensive instruments.

Problems Faced by Undergraduates Studying Electromagnetics

MATTHEW N. O. SADIKU

Abstract—The problems faced by undergraduate students studying electromagnetic theory have been highlighted. These problems have been found to be associated with the background of the students, the choice of textbook, and the instructor's teaching methods. Several recommendations are made to deal with these problems.

I. INTRODUCTION

It is generally admitted that one of the most difficult courses to teach in the electrical engineering curriculum is electromagnetic theory (EM). While EM is elegant in structure, it is especially rigorous in formulation and, therefore, unpopular to most students. Unlike other courses such as classical control theory and linear system, EM requires a lot of mathematical tools. This tends to make

most students regard EM as too abstract when it is actually based on experimental results. Except for the ones who are mathematically inclined, engineering undergraduates frequently feel uncomfortable with EM and shy away from it.

The objective of this paper is to identify the problems and difficulties faced by many students and offer some suggestions on how the problems can be alleviated. Some of the problems are associated with the students, while others are with the recommended textbook and the teaching methods of the instructor. The problems associated with the students are discussed first and possible solutions offered. Problems associated with the textbook and the instructor are discussed afterwards.

II. STUDENTS' BACKGROUND

Some of the students taking EM for the first time are weak in calculus and vector analysis. The weakness is sometimes due to the fact that they have taken calculus early in their college career and have forgotten much of it or, perhaps, did not learn it well in the first place. They may have had little or no exposure to topics such as triple integrals and complex variables, which parts of the EM course require.

These background problems may be solved partly by the text and partly by the instructor. The text could give a thorough but brief exposure to some fundamental concepts of vector analysis and probably complex variables. The instructor could supplement whatever the text is lacking through "brush-up" lectures or extra tutorials.

III. RECOMMENDED TEXTBOOK

Quite a large amount of textbooks have been published on EM. From 1950 to 1970 alone, over 80 books on EM were published, not including those mainly dealing with applications, such as antennas, waveguides, wave propagation, etc. [1]. Partial lists of these books, including those published recently (in the United States), are provided by Plonus [2] and Chen [3]. While some of the textbooks are well written, some are hard for the students to follow.

A good textbook on EM must do more than just provide materials to be learned. It should help the readers learn and build knowledge. This may be achieved in terms of orderliness of materials covered, giving enough solved examples to illustrate how concepts developed may be applied, giving enough exercises for the students to practice with and providing learning aids as appendixes.

Orderliness in the way the materials are presented is of primary importance. While most textbooks available now are logically ordered, some are not. The poor student is always lost after studying a section of a textbook only to find some "irrelevant" materials (so they appear to the student at least) in the next section. Lack of orderliness does not help the student to learn; it is confusing. A flow of thought from one paragraph to another, from one section to another, and from one chapter to the next helps the student grasp the subject matter and enjoy the learning process. However, orderly presentation of the materials needs to be done as succinctly as possible.

Learning how to apply the concepts developed in tackling problems is part of engineering education. It is, therefore, not enough to develop the concepts, no matter how elegantly, and give problems for the student to solve. Solved examples should be provided as much as possible. Examples should be clearly explained; otherwise, the student might not follow or benefit from them. Having the student fill in missing steps works only when the student understands the solved problems. Thoroughly solved problems not only help the students in solving other problems, they also help them grasp and assimilate the materials.

Review questions and problems at the end of each chapter are commonly provided [4]–[6]. Although review questions are good and intended to be thought-provoking, most students do not answer them. One way of presenting review questions and attracting the student's attention could be to provide them in the form of multiple

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choice. This idea has not been adopted by any textbook on EM. The idea may sound odd and untraditional, but if adopted and carefully practiced, it will surely help the students learn a lot more. The multiple-choice questions and the problems to be solved by the students should be carefully organized just as the main text. The problems in general should be presented in the same order as the materials in the main text and should be graded in difficulty, with relatively easy problems preceding hard ones. Enough problems should be provided to allow the instructor to choose some as illustrative examples.

Some learning aids which cannot be provided in the main text can be appended. Such aids may include mathematical formulas and identities, physical constants, and a brief review of materials such as vector analysis and complex variables, if not covered in the main text.

The question of whether an EM textbook follows an inductive or deductive approach should not pose a major problem to the student. An inductive approach presents the materials in historical order, starting with the experimental laws and finally synthesizing them in the form of Maxwell's questions. On the other hand, a deductive approach starts with Maxwell's equations, applies them to waves, and then deals with static and quasi-static situations as special cases. Each of these approaches has advantages and disadvantages. Whichever approach is adopted, it should be borne in mind that most of the students are getting exposed to EM for the first time and care must be exercised not to take too many things for granted.

IV. INSTRUCTOR'S TEACHING METHODS

The process of training is just as hard as that of learning. Just as the student of EM may be faced with some problems, the instructor of the course may find it hard to deliver the materials. Therefore, the instructor must be prepared to devise means whereby his ideas are effectively passed down to the students and the students can get the best out of the course.

One of the basic goals for the instructor who aims at producing quality students is that the students should get as much from the course as possible. The instructor may motivate the students to achieve this goal in several ways. Proper choice of the recommended textbook, orderly presentation of materials, emphasizing key points, giving examples, homework, and possibly quizzes may help.

Selecting a suitable EM textbook from the avalanche of new publications regularly appearing on the market should be carefully done by the instructor or his department. The selected textbook should contain the necessary basic principles and reflect the point of view of the instructor; otherwise, he may have to augment the textbook rather than follow it. An experiment on teaching effectiveness carried out by Zelby [7] indicates that his students considered him a good teacher when the textbook was followed and a poor one when he followed a point of view different from that of the textbook.

The importance of orderliness in presenting the materials cannot be overemphasized. According to Zelby, students seem to prefer the security of the textbook. It is easier for the student if the order of class topics follows that of the textbook, but the instructor may supplement areas where the book is weak. Also, it is necessary that the instructor link one subject or chapter to the next so that there is a flow of thought and the students can easily have a firm understanding of the subject matter.

Emphasizing the key points and ideas is essential to the students. This draws their observation to those points and particular attention is paid to them. It also helps the students to sort out the essentials from the nonessentials. Emphasizing the importance of vector analysis, for example, at the beginning helps the student pay special attention to the chapter where vector analysis is covered. Placing some emphasis on Maxwell's equations helps the student see the elegance of those equations.

Solving some typical examples in the class to illustrate basic con-

cepts developed usually helps the student more than anything else. Since time does not permit solving many problems in class, the examples should be carefully selected so that they are neither too simple nor too hard to follow. The key lessons in the examples should be clearly pointed out and emphasized.

No amount of input by the instructor will make students learn until they start doing things by themselves. Carefully selected homework problems can help them learn. The homework may or may not be submitted for grading depending on the instructor. If the instructor gives quizzes regularly enough, submitting homework for grading may not be necessary.

If the instructor desires, the Schaum Outline series on *Electromagnetics* [8] and the *Mathematical Handbook* [9] can be suggested to the students as learning aids.

V. CONCLUSIONS

To alleviate the problems encountered by undergraduate students studying EM, the three problem areas identified as dealing with students, textbook, and instructor should be attacked simultaneously if possible. It is strongly believed that if the ideas suggested in this paper are carefully followed, electrical engineering students will feel more comfortable with the EM course. They will not only derive interest in the course, they will be highly challenged and motivated. A good textbook will be greatly appreciated by the students and the instructor. The instructor also will have a sense of accomplishment when the students perform very well.

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Simplified Biot-Savart Law for Planar Circuits

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Abstract—A simplified formula for the magnetic fields of line currents is obtained for the special case when the line currents and the observation point are confined to a plane. Its application is demonstrated by several examples.

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