Assessment-Based Use of CAD Tools in Electromagnetic Field Courses

Milica Popović, *Member, IEEE,* and Dennis D. Giannacopoulos, *Member, IEEE*

Department of Electrical and Computer Engineering, McGill University, Montreal, QC, H3A 2A7, Canada

Undergraduate electromagnetic field courses entail significant teaching and learning challenges. The use of simulation technologies in these courses can be an effective teaching strategy if designed properly. An assessment-based approach for identifying difficult concepts to incorporate into simulation-oriented learning is investigated. The potential benefits of the approach are illustrated with a case study.

***Index Terms*—Computer-aided analysis, electrical engineering education, electromagnetic analysis, electromagnetic fields.**

I. Introduction

TEACHING undergraduate electromagnetics has historically been a challenge, as it requires extensive presentation of the basic theoretical and abstract concepts that underlie most electrical engineering principles [1]–[5]. Consequently, students are not necessarily enjoying the material nor learning sufficiently to understand its essential role in their global undergraduate curriculum. Therefore, the improvement of teaching electromagnetics courses has received notable interest over, at least, the last two decades [1]–[13]. One approach being increasingly employed for this purpose is introducing the use of computational analysis and design (CAD) tools in these courses [3], [7], [12], [13]. These types of simulation tools have the potential to significantly improve undergraduate students' knowledge and interest in electromagnetics [2], [6], [14], [15]. In particular, accurate and reliable CAD tools can help illustrate important engineering applications of electromagnetics theory without the need for expensive laboratory test facilities [3], [6], [7].

The aforementioned advantages can take effect only if the use of CAD tools in undergraduate electromagnetic fields courses is carefully designed. In a well-designed CAD tool-based teaching environment, the resultant benefit to student learning should justify the various associated implementation costs [1], [6], [7]. For example, a main theme to emerge during the panel discussion at Compumag 2003 was that CAD tools must be user-friendly and capable of providing near real-time feedback to the student. In addition, it should be noted that the time devoted to learning through interaction with CAD tools will, necessarily, be at the expense of available time for other teaching strategies [1], [3]. Hence, these learning requirements illustrate the possible value of a careful "needs assessment" of how CAD tools may be most effectively incorporated into electromagnetics undergraduate courses [2], [16].

The purpose of this paper is to investigate the potential benefits of employing specific assessment methods in order to identify which concepts appear more difficult for students to conquer. Subsequently, greater attention can be paid to these concepts while designing corresponding CAD tool-based teaching strategies in order to improve learning of these concepts in electromagnetics field courses.

II. Use of CAD Tools in Electromagnetics Courses

While the last several decades have seen an increased interest in using CAD tools to improve teaching and learning in undergraduate electromagnetics courses, it is important to consider carefully how this is implemented [1], [6], [7]. In some cases, instructors may be tempted to design CAD-based exercises in an *ad hoc* fashion, or motivated by the context of commercial electromagnetic simulation software accessible to them. This can result in, for example, computer-assisted exercises or design problems that are too advanced or not necessarily best suited to helping students overcome difficulties in learning the essential electromagnetic field concepts [1], [9].

In particular, it is important to note that, in order for students to benefit most effectively from CAD tool-based teaching strategies, they must first have a strong understanding of the fundamental concepts underlying electromagnetic field theory [1], [9], [10]. In fact, it has been suggested that without this students may be confused and intimidated by CAD tool learning involving more advanced topics or poorly designed examples [9]. Therefore, it is evident that we first need to *assess* which fundamental concepts are posing the most difficulties for student learning [2], [16]. Once these concepts have been identified, they can then be used to help design more effective CAD tool-based teaching strategies (e.g., simulations that help illustrate a fundamental concept graphically). Of course, such assessment strategies should, ideally, be versatile enough to accommodate the variations that will occur in different semesters and for different instructors of the same course.

Details of the assessment method employed and related findings are elaborated upon in Sections III and IV. In addition, a case study will be presented in order to illustrate how such results can yield insight in the effective design of CAD tool-based teaching strategies.

III. Initial Assessment Method

The need for effective assessment methods in undergraduate electromagnetic fields courses is especially important given the recent trends toward introducing increasingly more CAD tool-based learning, as noted above [16]. In fact, using the advantages of computer technology to improve student learning in

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TABLE I
ELECTROMAGNETIC CONCEPTS INVENTORY QUESTION-CONCEPT MAP [16]

Question #	Concept Covered
1	Coulomb's law; vector addition; usage of symmetry
2	Usage of symmetry; Gauss' law
3	Conservative nature of electrostatic field
4	Connection between (electrostatic) field and potential
5	Conducting bodies and influence of their shape in electrostatic field
6	Electrostatic induction and shielding
7	Air-conductor boundary conditions in electrostatics; image theory
8	Electric field within conductors in electrostatics
9	Capacitance – general concept
10, 11	**E** and **D** vectors in capacitors with inhomogeneous dielectrics; Boundary conditions at dielectric-dielectric interface; **D**=ε**E**
12	Current density vector; continuity and boundary conditions for time-invariant (DC) currents
13	Force on a DC-current-carrying wire conductor in a magnetostatic field; magnetic field due to a straight DC-current-carrying wire; vector addition
14	Torque on a current loop in a magnetostatic field
15	Ampere's law; DC-current distribution in a conductor cross-section
16	Law of conservation of magnetic flux
17	Law of conservation of magnetic flux; magnetic circuits; boundary conditions for the magnetostatic field; **B**=μ**H**
18	Curl and divergence; definition of field lines
19	Electromagnetic induction (Faraday's law): transformer emf
20	Electromagnetic induction: motional emf
21	Electromagnetic induction: combination of transformer and motional emf
22	Mutual inductance; lines of magnetic field due to a current loop
23	Maxwell's equations; generalized Ampere's law

these courses is considered by some educators not as an option, but as a critical requirement for successful curricular reforms in science and engineering [3]. Hence, careful attention must be given to the development and testing of assessment methods, which can be used to measure students' understanding of fundamental electromagnetics concepts [2], [16].

A. Evaluation Methods

In general, the technical content of an undergraduate electromagnetics field course may be organized into a number of major topics. Consequently, a collection of qualitative short answer test questions can assess the understanding of the core concepts underlying the course [4], [16]. Such a test in a multiple-choice format has several benefits [4]. For instance, it allows for a very directed and focused summative assessment of how well students understand individual or a few related fundamental concepts [1], [4], [16]. In addition, the multiple-choice format allows for questions to be designed with sufficient generality. A test comprised of such questions may be used by different instructors in a given semester in order to assess specific conceptual difficulties [1], [4], [16].

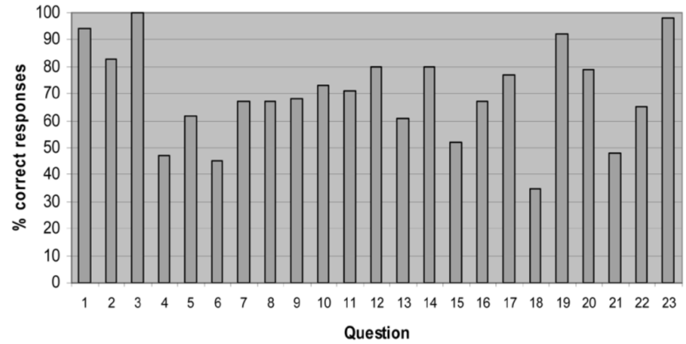
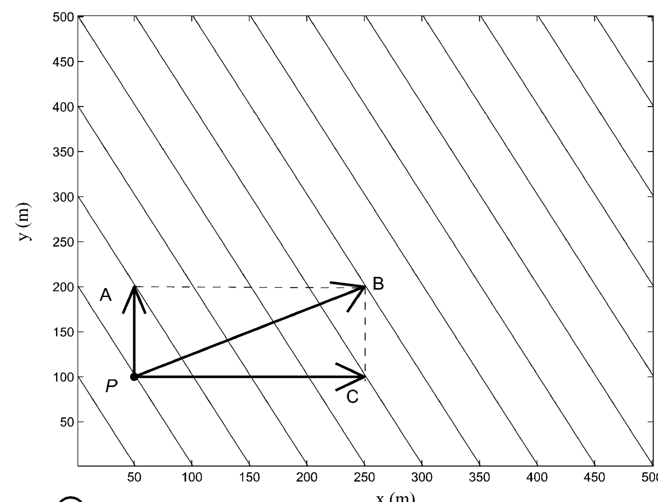


Fig. 1. Results of initial assessment (66 students were tested). The concepts related to question numbers are given in Table I.

Suppose a scalar, time-independent electric potential field in some region of space is given by $\Phi(x,y) = 200x + 100y$ volts, with x and y expressed in meters. In the figure below, which shows an equipotential plot of Φ in the *x*-*y* plane, select the vector at the point *P* that best represents the associated electric field **E**(x,y).



◎ A

◎ B

◉ C

◎ None of the above

Incorrect! The correct response is "none of the above". Hint: $\mathbf{E} = -\mathrm{grad}\Phi$.

Fig. 2. Question designed to test the concept of the gradient of a scalar field.

We found that the Electromagnetic Concepts Inventory (ECI) [16] offers an exam well suited for selective testing of introductory electromagnetic concepts. For completeness, Table I shows the question-concept map as designed within the ECI. Results obtained using the ECI test will help us identify subject concepts where improvement strategies are needed.

B. Initial Assessment Results

With reference to Table I, Fig. 1 shows the percentage of correct answers achieved for each question during the initial semester of assessment using the ECI. A total of 66 students participated in the one-hour ECI test. Interestingly, one of the most difficult questions for the students was #18, related to the graphical interpretation of divergence and curl of a vector field.

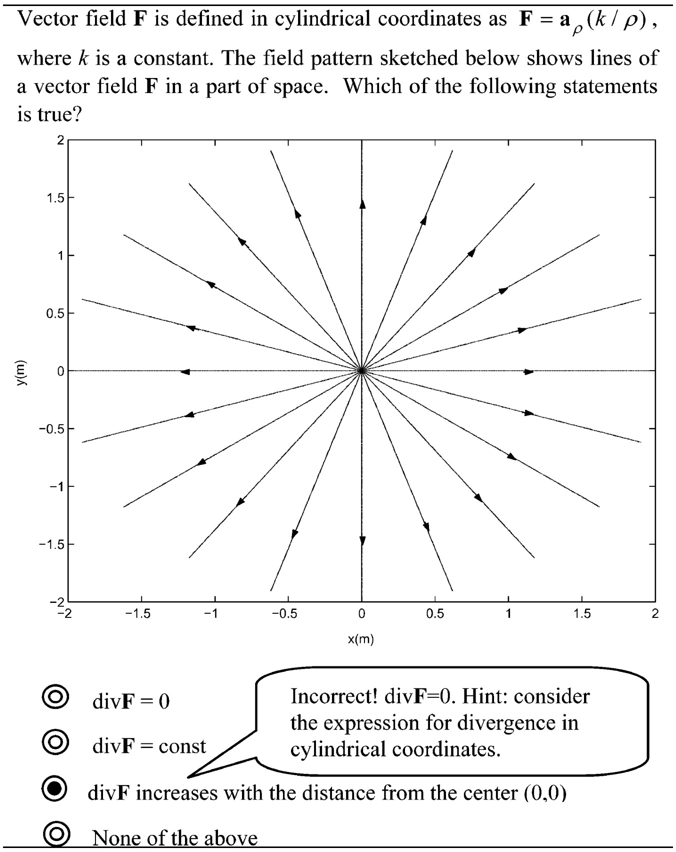


Fig. 3. Question designed to test the concept of the divergence of a vector field.

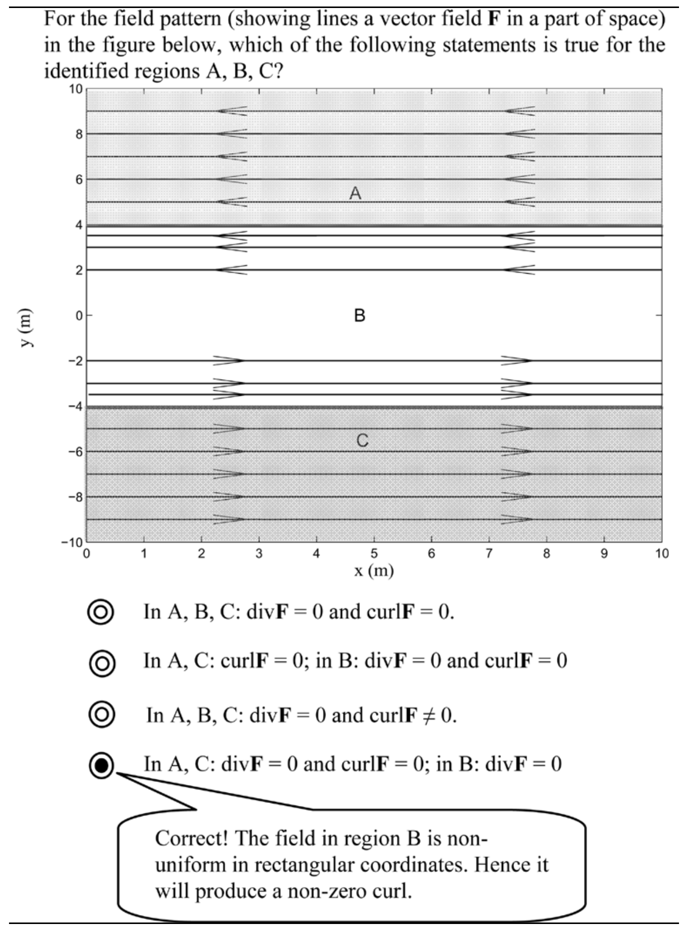


Fig. 4. Question designed to test the concept of the curl of a vector field.

(Difficulty with basic vector analysis concepts is not uncommon in introductory electromagnetics courses [4].)

Of course, these results are only relevant to the specific class and semester considered. However, the flexibility of the considered assessment method allows a particular instructor to use the results of each semester for a continuous update of concepts critical for electromagnetics fundamentals. In Section IV, a case study will be presented on how such results can be used to yield insight into the effective design of CAD tool-based teaching strategies.

IV. Case Study Results

Based on the results reported in the previous section, an effort was undertaken to design and implement teaching strategies that could improve our students' learning related to the fundamental vector field concepts. To this end, a series of interactive software exercises were developed for use during a subsequent semester that seem to have helped improve student learning. These tools are described in greater detail next, followed by a brief discussion of the noted improvement.

A. New Software-Based Learning Tools

There are numerous ways to incorporate CAD tool-based learning strategies in undergraduate electromagnetic field course [7], [12], [13]. However, for the objectives of this work, it was most appropriate to develop user-friendly, interactive software-based learning tools that could help improve student learning of basic electromagnetics concepts [1], [2]. The students registered for the course are encouraged to use these tools through the course web page.

Specifically, a series of interactive multiple-choice style exercises were developed to improve students' understanding of gradient, divergence, and curl of a vector. Figs. 2–5 show example screen-shots of some of these exercises. Problems related to vector analysis concepts are illustrated in Figs. 2–4. A plot, related question, and answer options presented to the student are shown in each figure. In the question illustrated in Fig. 5, the student is asked to identify if the field plot shown corresponds to a static electric or magnetic field, based on their knowledge of the correct divergence and curl properties of these fields. In each exercise, if the student selects an incorrect response a hint appears that is intended to help the student understand why the choice is incorrect. Alternatively, if a correct choice is made the answer is validated with a supporting explanation that appears on the screen.

B. Results

Following the semester in which the new exercises were introduced, there was a significant improvement noted in the percentage of students that were able to correctly answer question #18 of the ECI. Specifically, 72% of 54 students answered correctly compared to 35% in the previous semester (66 students).

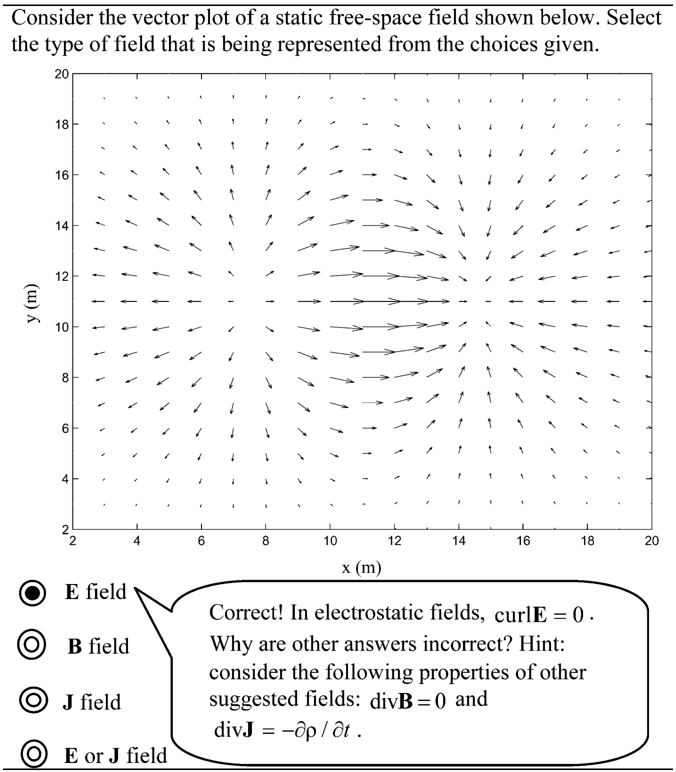


Fig. 5. Question designed to test knowledge of properties of electric and magnetic fields.

These results corroborate previous findings that interactive software-based teaching tools can improve student learning [1], [2]. More importantly, with respect to the objectives of this paper, the results suggest that using an assessment-based approach for identifying specific challenging concepts that can benefit from computer-based learning strategies, can be successful. We believe this is an important first step toward designing more effective CAD-tool based teaching strategies to improve learning in electromagnetic field courses.

V. Conclusion

In this paper, an assessment-based approach was investigated to identify difficult concepts and use them to optimize simulation-oriented learning tools for undergraduate electromagnetic field courses. This was illustrated through a case study, which suggested that this approach can lead to improved learning of specific fundamental concepts.

The following points may be of interest and value for future work. First, the assessment-based approach considered in this work could be used for the design of CAD tool-based learning of advanced and application-oriented examples. Second, the proposed approach can aid in evaluating the impact of simple exercises presented in this paper on students' ability to subsequently follow and benefit from CAD software involving complex application examples.

Electromagnetics is an integral part of every electrical engineering curriculum. Improved teaching of this subject continues to rightfully receive considerable attention. Careful design of such improvements can help the electrical engineering curriculum to continuously evolve in a positive direction. We hope that the approach suggested in this paper is a step in achieving this goal.

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