AC 2010-248: BLESSING OR CURSE, TEACHING WITH CAD SOFTWARE

Yumin Zhang, Southeast Missouri State University

David Probst, Southeast Missouri State University

Blessing or Curse, Teaching with CAD Software

Abstract

Computer-aided design (CAD) software packages are indispensible tools for scientists and engineers, and thus they are often introduced in many science and engineering courses. Depending on how they are used in class, these software packages can be very helpful or rather harmful to students' learning. With the understanding of theories, people can have deep insight and wide perspective of technical problems. On the other hand, a computer can simulate a well specified problem and give out the detailed solution. Therefore, human and the computer can complement each other and solve many problems effectively. CAD software packages are used in several courses in our department, including Electromagnetics and Electronic Circuits. We find that they can get students more interested in the subject, as well as help students to visualize physics concepts and also better understand the theories.

I. Introduction

CAD software packages are widely used in many science and engineering courses, such as Electromagnetics and Electronic Circuits. Many physical laws are expressed in the form of partial differential equations, such as Maxwell's equations. Unfortunately, there is no closed-form solution for most practical problems. With the help of CAD software, students can overcome this mathematical barrier. In addition, the capability in solving these equations can help students visualize the invisible physical variables, such as the distribution of electric and magnetic fields[1]. Furthermore, students can investigate practical devices by simulation, which can increase their interest in learning the abstract theory[2, 3].

In many engineering applications, there are many variables entangled together, such as in electronic circuits, and it also defies human's capability to solve them. In addition, many active electronic devices, such as transistors, have nonlinear behaviors, which further complicate the analytical approach. However, such problems can be efficiently simulated with the simulators in CAD software packages. Therefore, many engineering designs rely heavily on computer simulation, so it is imperative to teach students how to use these indispensible CAD tools[4,5].

Although CAD software provides huge benefits in the fields of science and engineering, it could also cause some negative effects for students if used without precaution. Because many software packages are so powerful, some students believe that the traditional process of learning fundamental concepts and theories can be bypassed and replaced. However, in industry engineers often face a vast design space and endless possibilities, therefore, the first step in choosing the design scheme relies on human insight and intuition. When the design space is narrowed down to a small range, CAD software can be used to further optimize the design.

From a certain point of view, the functionality of CAD software is just like a telescope, which has a clear but narrow vision. On the other hand, the astronomers need to decide where to look, which requires knowledge and experience. In addition, powerful telescopes can sometimes export artifacts, which need to be discarded from credible images. Similarly, the CAD software packages can also give unreasonable results, and one will be misled without a good understanding of the theories.

II. Teaching Electromagnetics

Electromagnetics is a rather challenging topic for many physics and engineering students, as the electric and magnetic fields are invisible and the mathematics is very complicated. Therefore, without the help of CAD software, students often feel that this abstract theory has little connection with the real world. As a result, students tend to memorize a few equations, but cannot apply them in practical problems. There are many advanced EM field simulation software packages available, and we adopted QuickField™, which is very easy to use and its limitation in 2D simulation is not an issue for this class.

The first project assigned in this course was in the area of electrostatics, and the topic was capacitive sensor. As the capacitance depends both on the geometry and the dielectric material, students designed many kinds of sensors. The simplest one is a pressure sensor based on a parallel capacitor, which is shown in Fig.1. The distance between the two capacitor plates is related to the external pressure; the higher the pressure, the larger the capacitance. On the other hand, the idealized theoretical model often assumes the electric field is confined between the two plates, but the simulation result shows clearly there is a wide range distribution of the fringe field. In addition, students can also investigate the electric charge distribution on the plates, electrostatic potential energy density and the total capacitance.

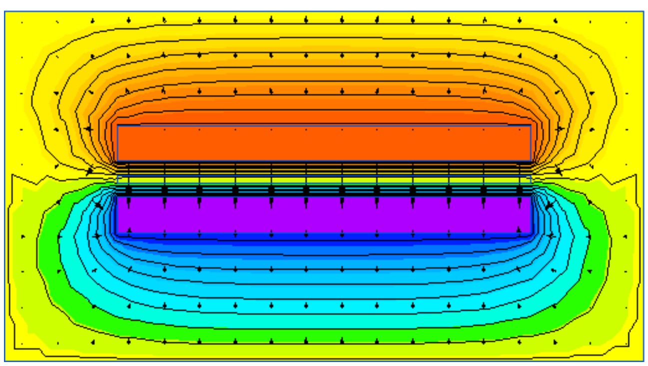
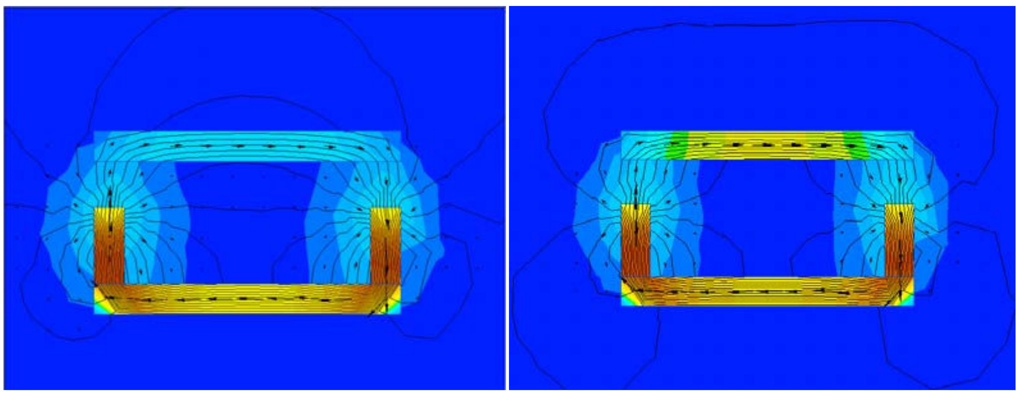


Fig. 1. Potential and field around a parallel plate capacitor.

The second project assigned in this course was in the area of magnetostatics, and the topic was on the effect of ferromagnetic material in a magnetic field. Many applications are related to this topic, such as the transformer and the antenna of an AM radio. First, students put two small magnets in space and found the distribution of the magnetic field by simulation. Second, a ferromagnetic material bar with the relative permeability $\mu_r = 100$ was put underneath the two magnets, and it was found that the magnetic field lines funneled into this bar just like water flows through a hose. Third, another ferromagnetic bar was put on top of the two magnets, which is shown in Fig. 2. Then the magnetic field distribution was investigated by changing the relative permeability (μ_r) of the top bar in the range from 1 to 1000. If μ_r is pretty low, there is little effect to the distribution of the field. Unlike the situation in electric field, the presence of non-ferromagnetic metals, such as aluminum and copper, has little effect on the distribution of static magnetic field. On the other hand, materials with high relative permeability can change the field distribution significantly. Figuratively speaking, materials with a high permeability are just like shortcut paths. As a result, the magnetic field is crowded into them, which is shown in Fig. 2(b). In addition, the software can also calculate the attraction force from the magnets.



(a) (b)

Fig. 2. Ferromagnetic material in magnetic field, (a) μ_r = 10, (b) μ_r = 1000.

The effectiveness of teaching Electromagnetics with CAD software is assessed in several different ways. There are two major objectives in this course: 1) understand the concepts and theories, 2) be able to solve problems with them. The first objective is addressed by the *Conceptual Survey in Electricity and Magnetism*[6], which was administered at the beginning and the end of the semester.

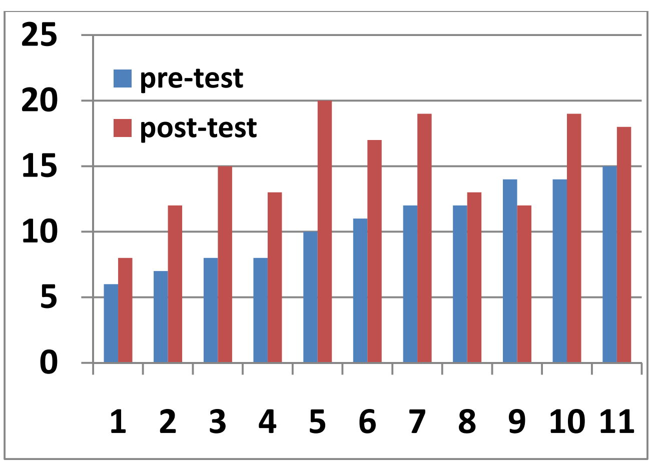


Fig. 3. Results of the conceptual survey.

Fig. 3 shows the result of this assessment: There are 32 problems, and eleven students participated in the survey, the average score increased from 10.6 to 15.1. The data was analyzed with the Student's T-Test, and the result is $p < 0.0012$, which indicates the significant improvement of the knowledge level in this subject[7].

In addition, such a survey can also reveal which concept is especially challenging for the students. For example, most students know that an enclosed conductor shell can shield an external electric field, but they think that it can also shield the field created by charges inside it. Therefore, this issue will be addressed the next time this course is offered. As a matter of fact, this problem can be conveniently analyzed with Gauss' law, or it can be learned by simulation with the software.

Second, the final exam scores are compared with the same class taught two years ago, which is an indicator of students' ability in solving problems. The average scores are 72.9% (previous) and 68.3% (current), respectively. Although these numbers are not significantly different and the class size is rather small, it implies a small downward slide. It is believed that the introduction of CAD software can increase students' interest in this subject; at the same time, it also made some students pay less attention to the challenging analytical skills in solving problems. In order to prevent students from getting software dependent, design projects were assigned during the second half of the course.

Finally, students' opinions were sought in the class evaluation process; in general they had very positive opinion of incorporating the CAD software in this course. One student wrote: "*The software was very helpful in comprehending the concepts of Electromagnetism. Even though it was limited to 2-D, it was still a great visual aid and learning tool*". Another student wrote: "*I enjoyed the simulation problems. However, I felt that we should have had more time with them, and started using them at the beginning of the class rather than the end*". Although most students enjoyed using the software, some of their simulation results had fatal flaws. Without a good understanding of the theory, these students were not able to identify the spurious results.

One of the challenges in teaching this course is the time constraint. Although the students had learned vector calculus as a prerequisite, most of them still had a hard time in understanding and using these formula and theorems. Therefore, a comprehensive review of vector calculus was needed at the beginning, which took about 30% of class time. In addition, during class some applications of electromagnetics were introduced, which also cut into the precious lecture time. Furthermore, teaching the usage of the software and discussing the design projects also took away some lecture time. As a result, there was rather limited time to cover more material during a semester. On the students' side, they need to spend considerable amount of time in learning how to use the CAD software package, as well as working on the design projects and writing lab reports. Hence, there is a time conflict between learning the theories and working on the projects. Comparatively speaking, learning the theories is difficult, but learning how to use a software package is relatively easy, and thus some students were biased towards the latter. It was noticed that the attendance rate dropped a little after the CAD software was introduced. This correlation needs to be further investigated.

III. Teaching Electronic Circuits

Another course in which computer simulation is extensively used is the analog electronics course. From the beginning of the course during the review of basic circuit analysis techniques through the detailed study of diode and transistor circuits, students are assigned weekly homework problems that they must work out analytically and then also by simulation. For many years we had used MicroCap as our simulation tool, but recently we switched to using Multisim.

For each problem, students must write a detailed discussion comparing and contrasting the results of the simulation with their manual analysis. This last step is critical for helping students adequately reflect on what the simulation is producing and whether or not the results are sensible and in reasonable agreement with their manual analysis. Experience has shown that these kinds of exercises truly reinforce for students the distinction between simple device models used in manual analysis and more detailed device models used in computer simulations. They also prepare students for professional practice by helping them gain basic proficiency with circuit simulation software.

IV. Conclusion

We believe that CAD software is a useful tool in teaching science and engineering courses, if it is used complementarily. First, it can overcome the challenging mathematical barrier and connect theory with reality. Second, it is helpful for student to visualize the invisible concepts and better understand their spatial distribution. Third, it can be used to design and simulate practical devices and investigate the influence of the design parameters. However, overuse of CAD software can be harmful to students, and their attention is shifted from understanding the concepts and theories to the skill in manipulating the software tools.

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