The Physics Behind Electromagnetics Concepts

By using simulation applications it is possible to visualize electromagnetic fields – for a better learning experience and successful future.

Brianne Christopher

Nate Kinsey, Assistant Professor at the Virginia Commonwealth University (VCU), recalls his first undergraduate course in electromagnetics as very tough: "A lot of smart people remember this course as the first one where things did not work without a lot of effort," he says. Fortunately, this experience did not discourage him: Kinsey received a master's degree from the University of Missouri Columbia and a PhD from Purdue, both in electrical engineering. He is currently researching integrated photonics and nonlinear optics while teaching undergraduate engineering students at VCU.

Kinsey used his experience as an impetus for introducing his students to simulation. Because the key to their success in such a course is the ability to actually visualize and gain intuition for the problems. However, this is not as easy as it sounds.

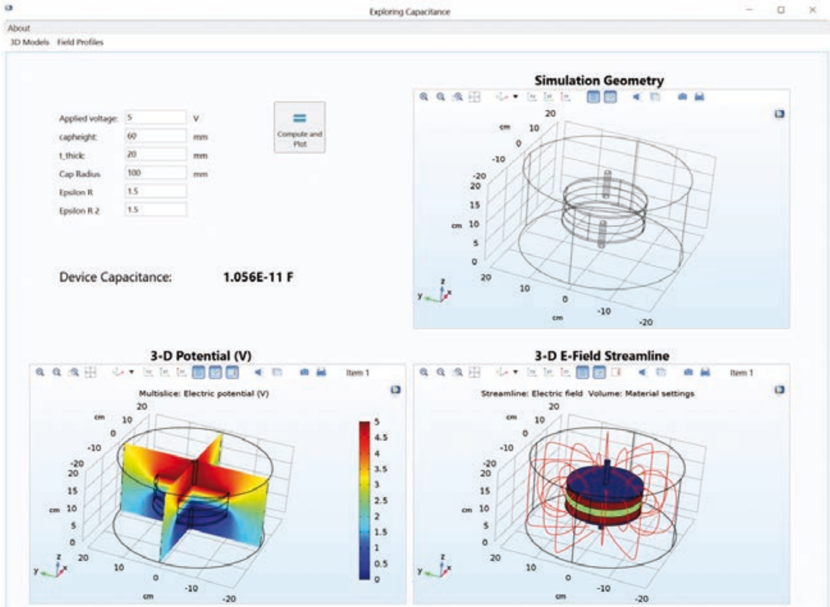

Fig. 1 This simulation application allows to study the fringe fields in capacitors.

To visualize the invisible

Electromagnetics courses involve rigorous mathematical formulas, 3D vector calculus, and some more. In addition these topics converge for the first time in a student's career, compounding the challenge. Because of this, many students get stuck in the complex mathematical formulas and equations without getting a clear picture of the actual problem they are trying to solve, which is integral to their success.

Thus, today's generation of students is struggling to get a picture of an object or problem in their mind's eye. But what this generation of technology enthusiasts is very good at is returning to the image as soon as they have a visualization in their minds. They only need support to get there.

In terms of electromagnetics, students have a poor understanding of what the EM fields around their phones or a cell phone tower actually look like because they cannot see or interact with them; they appear abstract. To a certain extent, Kinsey uses water waves and acoustic waves as substitutes for electromagnetic waves because they are much easier to visualize and relate. This helps students gain an intuition for the effects and physics that mathematics tries to describe. The problem is that these waves do not accurately represent the 3D electromagnetic problems.

"Students need 3D visualizations to see real electromagnetic problems, such as a magnetic field around a dipole," Kinsey explains. He illustrates these concepts on the blackboard, but drawings don't help all students. This is where simulation comes in. COMSOL offers the possibility to visualize electromagnetic fields, rotate, scale and interact with them, e.g. to

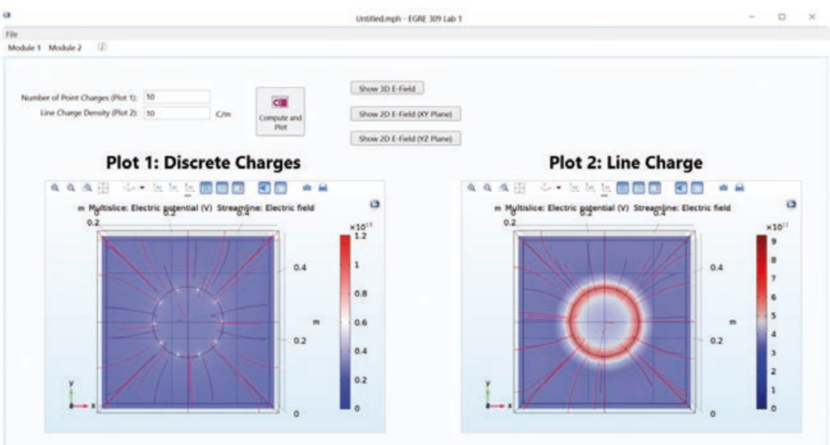

Fig. 2 A simulation application to compute discrete and continuous charges.

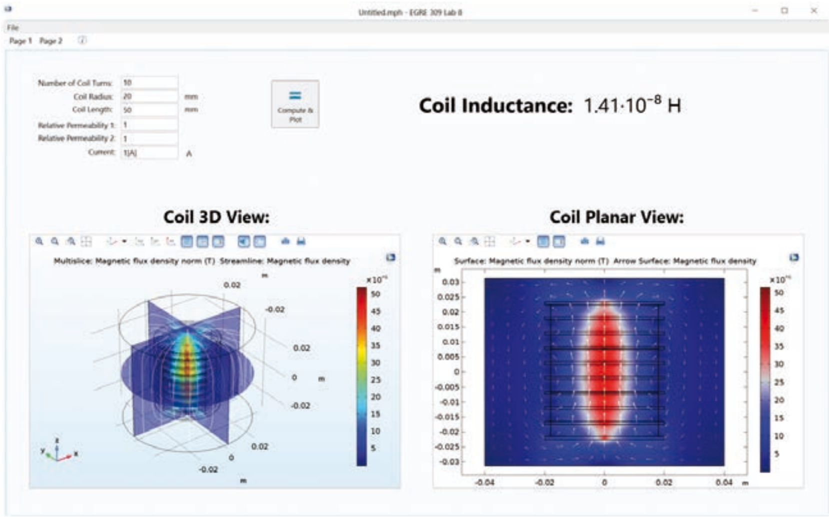

Fig. 3 An application for computing coil inductance and fringe fields, with settings for adjusting the coil geometry and other set parameters.

see how fields move around a dipole – which is difficult to display on the blackboard.

Helpful simulation applications

Although they are based on theoretical concepts, simulations can significantly improve students' understanding. In 2017, Nate Kinsey helped redesign the electrical engineering curriculum at VCU to improve student achievement. Simulation applications integrated with COMSOL Multiphysics® software help students achieve this goal. "Applications allow students to see and interact with a phenomenon at their own pace," Kinsey says. Since the curriculum already covered a large amount of material, it shouldn't be further overloaded by the task of learning a new simulation software. Instead, his class's teaching assistants create and package applications based on the concepts taught and upload them to the university instance COMSOL Server™, where students can access and run the applications for their tasks.

"We give them five to seven parameters to play around with, enough to be interesting but not enough to bog them down in details," says Kinsey (**Fig. 1–3**). Simulation labs are carefully designed because too much of a process or too much teaching inhibits students' critical thinking skills. Instead, students receive an application and are asked open questions, such as: "Using the application, show that the electric field of a sphere drops as $1/r^2$" (**Fig. 4, 5**). By not telling the students to set certain numbers or parameters, they actually have to think. In this way, they must ask themselves: "What else do I need to measure? What parameters do I need to sweep? How can I justify my answer?" If students get a wrong answer or don't find the information they need, they have to try again and grow on their mistakes.

Kinsey's electrical engineering course is designed as a two-week tandem cycle of simulation lab and hands-on experimentation, supported by lectures and recitation. In the first week, students explore key topics from lecture to numerical simulation, and in the second week they conduct actual experiments. These are intended to show that the concepts are not just fancy numerical tricks, but real physical effects. Here the students compare their measurements with the simulation results and discuss how things differ and what the reasons might be.

As with any such change, it took some time for the simulation applications to become popular. Initially, Kinsey had problems finding the right mix of difficulty and freedom in the simulation tasks. In addition, some of the students found that solving their simulations took a long time. This was a good opportunity to show the trade-off between accuracy and speed in simulation software – a valuable lesson for tomorrow's engineers.

Training the next generation

Students of the Bachelor's degree in Electrical Engineering at VCU take three things in particular with them from the course: First of all, they should develop a feeling for how electrical charges affect other electrical charges without getting discouraged by the difficulty of the problems.

Secondly, students should leave the course as agile, critical thinkers who are able to tackle tangential, real-life problems. This includes thinking about the rules of electromagnetics without learning them by heart. For

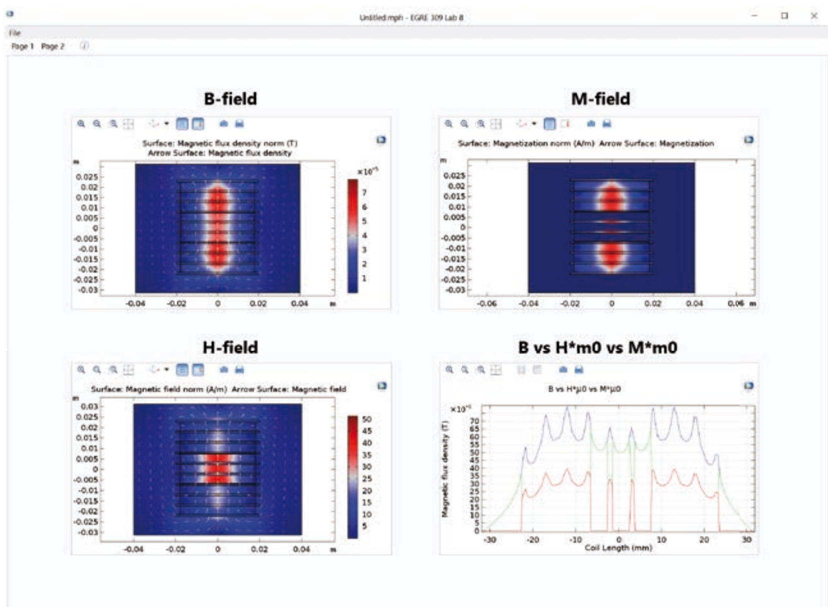

Fig. 4 Results of a simulation application that can be used to solve for magnetic fields and magnetization.

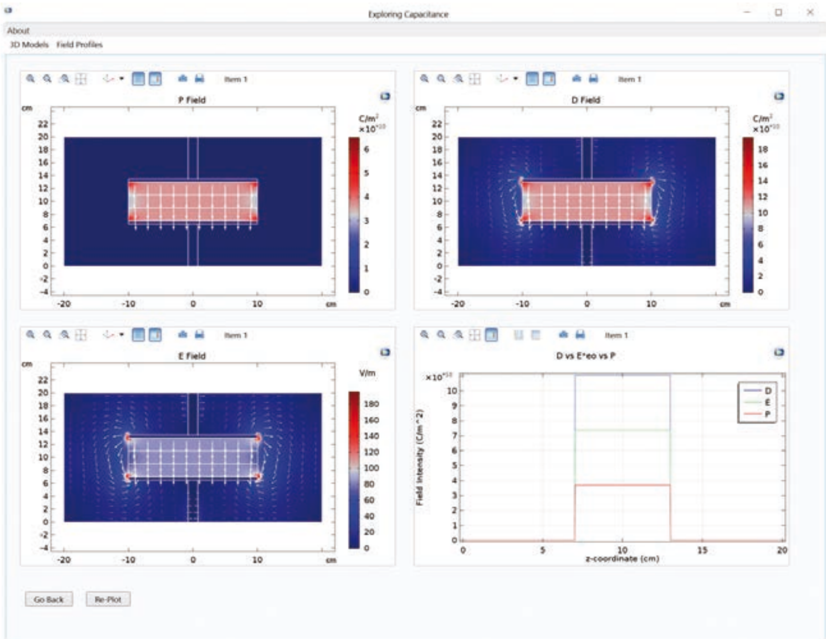

Fig. 5 Simulation results of an application that calculates electric fields in dielectrics.

example, instead of spitting Gauss' law out of their heads, they should ask themselves what it really means.

The third goal is to be able to see the convergence of areas in electromagnetics on a higher level, e.g. how mathematics and physics come together. For example, a student can solve a line integral without any problems, but if he has to calculate the potential difference from point A to point B, he is confused, even though the problems require essentially the same mathematics. If the students go beyond a "copy and paste" way of thinking, they can see mathematical formulas as tools. "It's like learning how to use a hammer," Kinsey says. "You start by practicing just hammering a bunch of nails, but at some point you have to go beyond that and build something."

The future courses at VCU

Always looking for new and better ways to integrate his students into learning, Nate Kinsey has big dreams of one day including virtual or augmented reality (VR, AR) in his curriculum. This would provide students with a haptic experience of ordinary engineering scenarios to help them understand the problem so that they can really immerse themselves in EM fields, capacitors and dielectrics.

Author

Brianna Christopher, Senior Content Manager, COMSOL, Inc.