ILLUMINATING THE PHYSICS BEHIND ELECTROMAGNETICS CONCEPTS WITH SIMULATION APPLICATIONS

Electrical engineering students at Virginia Commonwealth University are able to visualize electromagnetic fields using simulation applications — for a better learning experience and successful future.

By **BRIANNE CHRISTOPHER**

NATE KINSEY RECALLS HIS FIRST UNDERGRADUATE COURSE IN ELECTROMAGNETICS... It was tough. "A lot of smart people remember their electromagnetics course as the first course they experience where things do not work without a lot of effort," he says. "It was eye-opening."

Fortunately, the experience did not leave him discouraged: Kinsey went on to pursue 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 Virginia Commonwealth University.

Kinsey used his experience in that first electrical engineering course as an impetus for introducing his students to simulation. The way he sees it, the key to student success in such a challenging course is the ability to actually visualize and gain intuition for the problems. However, it is not as easy as it sounds.

» HELPING ELECTRICAL ENGINEERING STUDENTS VISUALIZE THE INVISIBLE

ELECTROMAGNETICS COURSES INVOLVE RIGOROUS MATHEMATICAL FORMULAS, 3D vector calculus, and more — plus, 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 Kinsey believes is integral to their success.

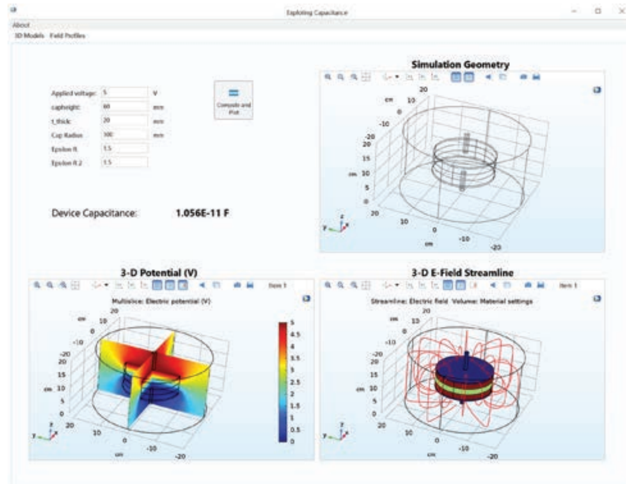

Figure 1. A simulation application that students can use to study the fringe fields in capacitors.

In fact, Kinsey has observed that the current generation of students struggle to create a picture of an object or problem in their mind's eye. What this technology-immersed generation *is* great at, however, is recalling the image once they *do* have a visualization in their mind. They just need assistance getting there.

In terms of electromagnetics, students have a poor understanding of what the EM fields around their phones or a cell tower actually look like because they cannot see or interact with it; they seem abstract. To a point, Kinsey uses water waves and acoustics waves as a stand-in for electromagnetic waves, because the former are much easier to visualize and relate to, helping students to gain intuition for the effects and physics the math is trying to describe. The problem is that these waves do not accurately represent 3D electromagnetics problems.

"Students need 3D visualizations to see real-world electromagnetics problems, like a magnetic field around a dipole," explains Kinsey. He illustrates these concepts on the board (so the field around the dipole looks like either a circle

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>
> —NATE KINSEY, VIRGINIA COMMONWEALTH UNIVERSITY

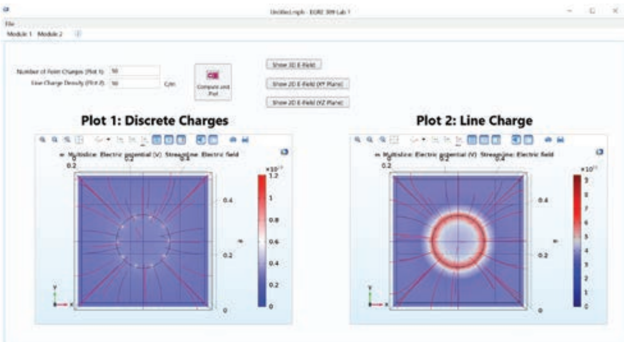

Figure 2. A simulation application for electromagnetics students to compute discrete and continuous charges.

or figure eight depending upon the viewing angle), but drawings can only accomplish so much. "Some students will get it," Kinsey says, "while others struggle." This is where simulation comes in. "COMSOL exploits the ability to visualize electromagnetic fields, rotate them, scale them, and interact with them; such as to see how fields curve around a dipole. This can be difficult to accurately convey by drawing on the board," says Kinsey.

ENABLING STUDENT SUCCESS WITH THE HELP OF ELECTROMAGNETICS SIMULATION APPLICATIONS

ALTHOUGH FOUNDED IN THEORETICAL CONCEPTS, Nate Kinsey believes that the addition of laboratories and simulation tools greatly enhances the student experience. In 2017, he helped redesign the electrical engineering curriculum at Virginia Commonwealth University in an attempt to bolster student success.

To do so, Kinsey added simulation applications built in the COMSOL Multiphysics® software to the course curriculum. "Applications enable students to see and interact with a phenomenon themselves, and at their own pace," he says. Since Kinsey's curriculum already had to cover a large amount of material, he did not want to add the task of learning a new simulation software onto his students' plates. Instead, teaching assistants in his class build and package applications based on the concepts being taught and upload them to the university's instance of COMSOL Server™, where students can access and run the applications for their assignments.

"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 (Figures 1–3). Moreover, simulation labs are carefully designed, as prescribing too much of a process or giving too much instruction inhibits the students' critical thinking skills. Instead, students are provided with an application and asked open-ended questions, such as: "Using the application, show me that the electric field of a sphere falls off as $1/r^2$" (Figures 4–5). By not telling students to set specific numbers or parameters, they "actually have to think," he explains. This approach gets them to ask themselves: "What more do I need to measure? What parameters do I need to sweep? How can I justify my answer?" If students get an answer wrong or do not find the information they need, Kinsey says it is a good experience for them to have to try again and grow from their mistakes.

Kinsey's electrical engineering course is designed as a two-week tandem cycle of simulation lab and hands-on experiment bolstered through lectures and recitation. During the first week, students explore key topics from lecture through numerical simulation, and in the second week of the cycle they perform the actual experiments, which are designed to show that the concepts are not just fancy numerical tricks but real physical effects.

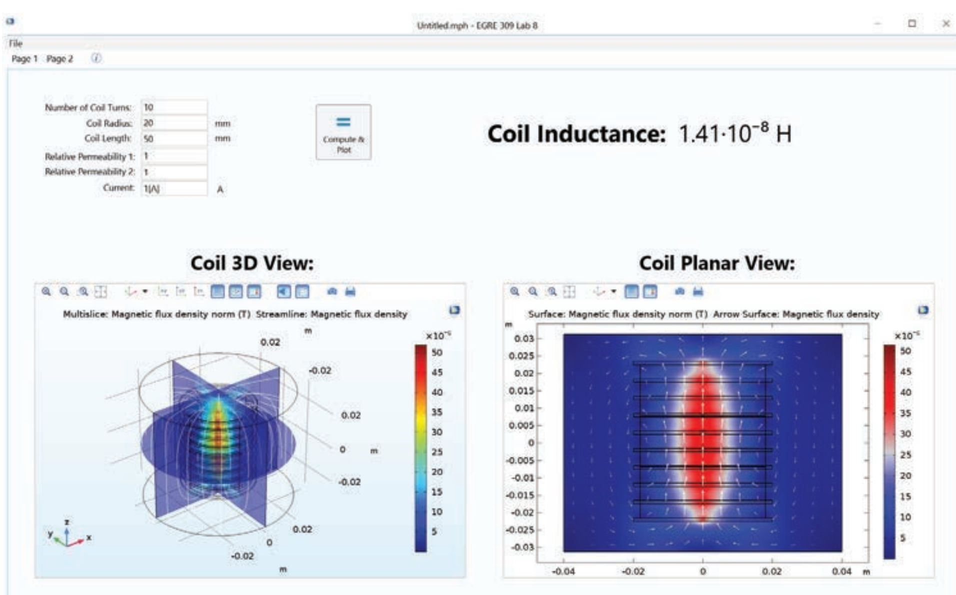

Figure 3. An application for computing coil inductance and fringe fields, with settings for adjusting the coil geometry and other set parameters.

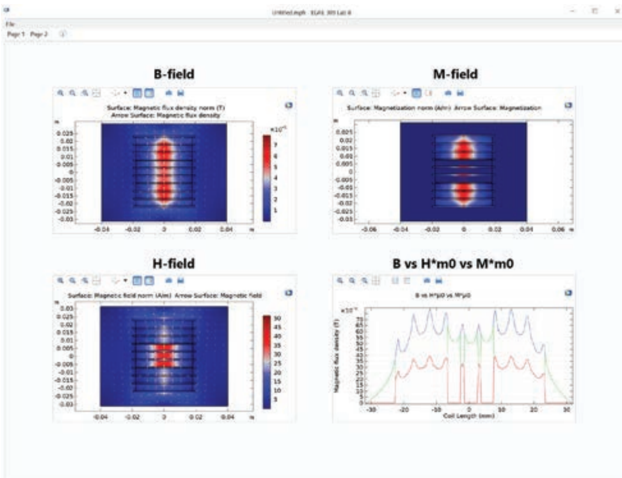

Figure 4. Results of a simulation application that students can use to solve for magnetic fields and magnetization.

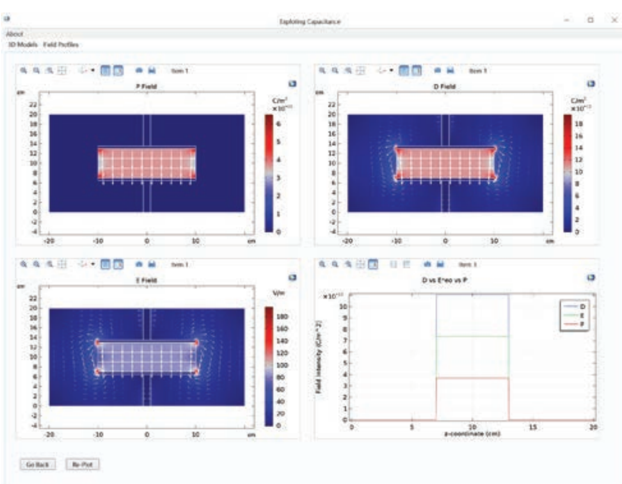

Figure 5. Simulation results of an application that calculates electric fields in dielectrics.

Here, students compare their measurements to the simulation results and discuss how things differ, as well as potential reasons why.

As with any shakeup to an educational institution, simulation applications took some time to get right and become popular. At first, Kinsey struggled to get the right mix of difficulty versus freedom in the simulation assignments. Also, some of the students noticed that their simulations were taking a long time to solve. Kinsey saw this as a good learning opportunity to show the trade-off between accuracy and speed in simulation software — a valuable lesson for tomorrow's engineers.

PREPARING THE NEXT GENERATION OF ELECTRICAL ENGINEERS

UNDERGRADUATE STUDENTS IN ELECTRICAL ENGINEERING at VCU get three main takeaways from Nate Kinsey's course. First of all, he hopes that his students are able to develop an intuition for how electric charges affect other electric charges without getting discouraged by the difficulty of the problems. "Electromagnetics is very very easy to make very very complicated," says Kinsey. "At the heart, all you are trying to do is find forces between charges — it is as simple, but as difficult, as that."

Second, Kinsey wants his students to leave his class as agile critical thinkers who are able to address tangential, real-world problems. This involves thinking about the rules of electromagnetics without memorizing them. For example, instead of being able to spout Gauss' law from the top of their heads, he wants his students to ask themselves: "What does Gauss' law tell me and what does it really mean?"

The third goal that Kinsey has for his students is that they can recognize the convergence of areas in electromagnetics on a higher level, such as how math and physics come together. For example, a student might be able to solve a line integral with no problem, but ask them to calculate the potential difference from point A to point B and they get confused, even though the problems essentially require the same mathematical steps. By moving beyond a "copy-paste" line of thinking, students will be able to see mathematical formulas as tools. "It is like learning how to use a hammer," says Kinsey. "You start by practicing just hitting a bunch of nails, but at some point you have to move beyond that and build something."

THE FUTURE OF ELECTROMAGNETICS ENGINEERING COURSES AT VCU

ALWAYS LOOKING FOR NEW AND BETTER WAYS to immerse his students in learning, Nate Kinsey has big dreams to someday incorporate virtual or augmented reality (VR, AR) into his engineering curriculum. AR or VR would be a path to give students a more tactile experience of common engineering scenarios, allowing them to basically go inside the problem and truly immerse themselves into EM fields, capacitors, and dielectrics. "It will be interesting to see how some of these emerging technologies become more cost effective in terms of teaching students, and how simulation plays into that," Kinsey says. ◎

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