

University brings PDEs to life in undergraduate education

An undergraduate heat transfer course uses COMSOL Multiphysics to help students design the cooling for a motorcycle engine block

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Although personal computers have brought major changes to higher education, a debate continues as to when is the appropriate time to introduce certain topics that seriously rely on computational power. For instance, is simulating partial differential equations (PDEs) using finite element analysis (FEA) suitable

through projects in what is known as the “paper-poster-presentation” paradigm. Those designs, however, are done on paper, and educators are trying to introduce the concept of “design-build-test” to help students learn by encountering problems, making mistakes, and overcoming them.

ods; one team even used a block of ice.

Keeping an engine running taught thermodynamics concepts, but students didn't yet understand heat transfer effects. I thus decided that for my second semester heat transfer course that I would extend the steam engine idea. However, I found that its cooling requirements resulted in a very simple problem to solve. Therefore, I decided to have them design an air-cooled motorcycle engine block and then study it using modeling software. The cooling requirements of such an engine are not trivial and thus made for a challenging project.

Although finite element modeling is usually absent from undergraduate courses, I saw this as an opportunity to introduce them to a new skill, and even more as a way to help them understand the fundamental physics and practical applications of the PDEs they saw in their textbooks, but never really embraced or even understood.

For this project, the only choice of software for me was COMSOL Multiphysics. True, I could have taught heat transfer modeling with any number of codes or packages, but only COMSOL supplies an intuitive menu structure and graphics-driven user interface where the equations are clearly visible, thus making it suitable for student use. In addition, it also provides direct access to the un-

for an undergraduate class? My recent experiences with COMSOL Multiphysics show that it can be done. Such an approach not only gives the students an introduction to a new tool and new knowledge but also motivates them to master these concepts when they later study them in detail.

Engineering education has moved far beyond the traditional chalk-and-talk lectures and examinations. Many programs now incorporate student participation

It started with thermodynamics

Last year, along with a colleague, Dr. Eric Constans, I introduced this concept into my first semester junior-level thermodynamics course and his mechanical design course. Student teams built steam engines and air compressors from scratch using raw metal stock. They discovered – through pistons seizing, for instance – that a major part of the task is keeping the cylinders and components cool enough. They tried various meth-

Dr. K.K. Bhatia (center) discusses the engine-block simulation with students Chris Rowen (left) and Dave McKenna.



derlying equations. I wanted to do more than teach them how to use a black box to get pretty pictures; I wanted to teach them the concepts. I decided to start small with a relatively simple project so they could get some experience working with PDEs. Then, when they later take a course in FEA, they will have a stronger motivation for paying attention to aspects such as boundary conditions or solvers that otherwise might seem somewhat arcane.

Let's get to work

Here's the way the project ran: The students first heard a 1 hour introduction to finite element analysis, after which they got a 1 hour introduction to COMSOL Multiphysics focusing on CAD import, manipulating PDEs, boundary and sub-domain conditions, getting a mesh and a solution, and generating postprocessing plots.

Next came a half-hour discussion of the project details: to design the engine block for a V-twin air-cooled motorcycle engine. The rough specifications for bore, stroke, vee-angle, and block material came from a Harley-Davidson® engine. The students were to design a block that would stay at a temperature lower than 350 °C while cruising at 60 mph.

The students' real work started with an analysis on paper of a simplified block design, making a first guess at the number of cooling fins, their geometries, and sizes. Then, using assumptions and hand calculations, they arrived at a rough answer for the heat generation and dissipation from the running engine.

Then they moved to actual design. They drew the engine block and its cooling fins in SolidWorks®, which they have access to in our computer lab and had used since their freshman year. After they created the 3D geometry, it was brought into COMSOL Multiphysics using the CAD Import Module.

The results at this stage were already interesting. Roughly half of the teams came up with conventional designs,

while the other half let their imaginations run wild and put cooling fins in odd locations. For instance, one team placed huge fins across the cylinders. At times like this I would inject some manufacturing concerns, which sometimes meant they had to do a redesign.

"No risks, no gain"

With the CAD geometry in COMSOL, they could then set up the model and generate a plot of the block's temperature. Some students used the Heat Transfer Module while others simply modeled the steady-state heat conduction equation (Laplace equation) using the Coefficient Form. Next year, I might require all to use the Coefficient Form because it will involve more exposure to raw PDEs. Whether a conventional or unconventional design, in about half the cases the modeling results were within 10 °C of the hand calculations. In fact, comparing the hand calculations to the model results not only made them comfortable with the model results but also drove home the important lesson of not putting blind trust in them.

"Bringing modeling and simulation tools into a course has tremendous advantages"

In that regard, I believe that students can learn a great deal through their mistakes, or as I like to say, "no risks, no gain." I wanted my students to have a chance to fail because with SolidWorks and the COMSOL Multiphysics live-connection they can quickly reiterate a modified design.

No black boxes or canned projects

When some of my colleagues learned about this project, they were afraid that it was too ambitious because it wasn't a "canned" project available in a textbook. They also questioned whether there would be enough time to pull it off. In the end, the project was a complete success.

One of my main goals was to make the students comfortable with PDEs

so the next time they ran into one they wouldn't be afraid to deal with it. With any other simulation tool except COMSOL Multiphysics this wouldn't have been possible. They'd likely be working with the PDEs "blind" as if the tool were a black box, and they wouldn't have direct access to the equations. It was also great that the students kept within the time plan—the teams spent roughly 15 hours on the project including the CAD design and model analysis. Almost universally, the feeling among the students is that "modeling is really cool!"

Adding experiments and verification

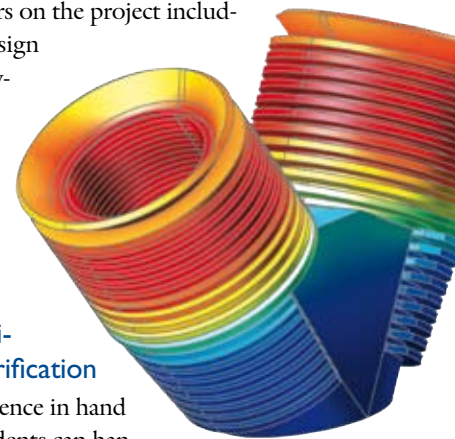
With this experience in hand I know that students can handle the software and the PDEs, and so I want to complete the design-build-test cycle. Thus, in my next undergraduate course, on advanced heat transfer, students will not only design something using COMSOL Multiphysics, they will also build it and compare experimental data to model results. One idea is to design a cooling device for a computer CPU. Not only will they go to the machine shop and manufacture a heat sink, they'll later attach thermocouples and take temperature measurements.

It's clear to me that bringing modeling and simulation tools into a course has tremendous advantages. I wouldn't be surprised to see it become a standard element of undergraduate engineering education in the near future. ■

AUTHOR'S BIOGRAPHY

Dr. Krishan K. Bhatia joined the faculty in Mechanical Engineering at Rowan University as an assistant professor after completing his PhD at the Pennsylvania State University. While at Rowan University he has focused his efforts on direct methanol fuel cells and advanced powertrain vehicles.

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Temperature distribution in the engine block of a motorcycle engine.