

From the Mind's Eye to 3D Animation: Teaching Electromagnetism with Learning Technology

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From the Mind's Eye to 3D Animation: Teaching Electromagnetism with Learning Technology



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Why use technology?

I turned to animation technology – and substantially changed the way I teach – for a very good reason: At the end of my third year of teaching MIT's 700-student freshman Electromagnetism class, I had figured out how to do it in the traditional format. I got very good student reviews and received a teaching award (the Physics Department's 1994 Buechner Teaching Prize). But, given all that, I would still only have 60-percent attendance in lecture at the end of the course because the students didn't need to come. They knew they could learn what they needed from the book. They did well on the tests I gave them, but quite frankly I think it was rote learning. They had seen enough of these problems to know how to do them. And that's what we were testing them on, not on conceptual understanding.

I've taught electromagnetism at a variety of levels from graduate to upper-level physics major to freshman. I think at all those levels people have trouble visualizing what you're talking about because it is very mathematical. You certainly absorb the mathematics, but a lot of this material is so complicated that you never really understand totally what's going on. So visual illustration really helps – even for a professional.

At research universities like Berkeley or MIT we tend to focus on the 5 percent or less of students who are going to continue in physics. I am more interested in helping the other 95 percent get a better grasp of the beauty of the subject, to impart a sense of wonder in my students about electromagnetic phenomena – phenomena that can only be seen in the mind's eye.

The strategy

I started with a software package for the Macintosh called *Theorist*, which is similar to *Mathematica*. This package allows you to do a lot of mathematics, and it also allows you to animate things. For example, when working with a function, you can change the parameters and watch how the function changes as the parameters change, and you can make a little movie of it. I started using that in teaching freshman physics and got really enchanted with what you could do with animation; it was very different from what we normally do. For a 700-student course, which is really hard to teach, if you find something that helps you get their attention and deliver information, you really pay attention to that tool.

So at first I was interested in animation and really focused on software and animation tools. Then I started going to American Association of Physics Teachers (AAPT) meetings, because I wanted to see if anyone else was doing this. I didn't meet a lot of other professors from research

universities there – for many reasons we as a group don't go to education-centered conferences – but I did get introduced to a lot of other things that people were doing.

I began using the Chabay and Sherwood electromagnetism textbook, which is based on physics education research. The textbook has an experiment kit (one of the reasons I used it) that allows you to do some simple circuit experiments. The students would bring their kits to lecture and we would all do these experiments. I also used a lot of peer instruction with ConcepTests, developed by Professor Eric Mazur at Harvard. I would pose a question and the students would work in pairs to answer them. I would lecture for 20 minutes, and then we would do a Concept question or one of the experiments, just to break up the lecture format. I also adopted Mazur's technique of requiring the students to read some material and be quizzed on it for credit before the lecture. This helped make up for the fact that you can't cover as much material with these innovative teaching methods as you could with traditional "talking at the students" teaching.

Using animation to teach electromagnetism is a qualitative change in how you can teach it. Animation can give you access to levels of abstraction that you just can't get to with the math alone. It's particularly valuable for students who are trying to understand things at a conceptual level, because there is not too much intuition about electromagnetism. Students have some intuition about mechanics, although their intuition there may be wrong, since intuition with mechanics tends to be oriented in a friction-dominated world – this is not what we teach in freshman physics. But at least they have some gut feeling for how things go in mechanics. In contrast, electromagnetism is largely hidden from their reality.

The course

Every undergraduate at MIT has to take two semesters of physics. This is not "Physics for Poets"; it is a quantitative college physics course. Students generally take Mechanics in the fall of their freshman year and take Electromagnetism in the spring. The spring E&M class is the large, 700-student class that I have taught. Now I teach electromagnetism in the off-term, with a class of about 110 students. These are usually freshmen who have placed out of Mechanics and are ahead of the game, or students who either didn't take Electromagnetism their freshman year for some reason or who are repeating E&M because they didn't pass it the first time. I always also have a few seniors who are trying to finally pass E&M to graduate. It's a really diverse audience of predominantly nonphysics majors, mostly engineers. The class meets for three one-hour lectures per week.

The learning technology

3D Animations: A lot of the demonstrations that you see on the Website are used in experiments that I do in lecture. I do the demonstration and then I'll tell the students, "The things that you can't see I'm going to show you in this visualization." You can see some smaller versions of these on the Website: <http://web.mit.edu/jbelcher/www/anim.html>. These are at a lower resolution than I use in class because I want them to come across the Web reasonably fast. The files I use in lecture are much larger, at much better resolution.

I use two different programs to create the visualizations, which are 3D animations. These are not cartoons. We first take videos of actual demonstrations. Then we create a 3D version of them on a computer, complete with field lines showing the electromagnetic forces at play. The mathematics – the field configurations and dynamics – are calculated quantitatively on a Sun workstation using *Maple*, a powerful computational software system (<http://www.maplesoft.com>). Then I import the results of that into a commercial animation

package, *Kinetix 3D Studio MAX 3.0*, so that the field lines are embedded in the animation as three-dimensional “tubes.” If electromagnetic fields were visible, this would be exactly what they look like.

The animations, such as “Magnet Falling through a Ring with Non-zero Resistance” and “Point Charge Attracted to a Charged Sphere,” help my students visualize vector fields and other electromagnetic phenomena that they have a hard time conceptualizing from just the mathematics. When the students look at the topology of the moving field lines, they can understand intuitively many properties of the forces transmitted by the fields.

Java applets: I also use Java applets in lecture in addition to what I call “passive” animations. They’re not as pretty, being basically 2D, but they still get the point across. And the students can interact with them in terms of changing the parameters, and so on.

Hardware: I’ve got a really nice classroom, outfitted with a really beautiful LCD projector and an Internet connection. I hook up my computer to the LCD projector and a lot of other nice audio-visual equipment. I use a very fast laptop computer to handle the very large video files.

WebAssign: For homework, I incorporate both the applets and animations into an automated, Web-based homework submission system, called “WebAssign,” developed at North Carolina State University (<http://www.webassign.net/info/>). This is another tool I learned about at an AAPT meeting. You can put your own problems into WebAssign and link in Java applets or animations – it’s pretty simple. You can use a multiple choice or numeric answer scheme. I use WebAssign for assignments that are due roughly an hour before lecture; I ask students to do some simple reading and answer simple questions about the topic of the lecture. This way the students are prepared for lecture, and it compensates for the material we don’t get to in class because of the demonstrations and Concept questions.

The project support

I have gotten a lot of internal MIT support from a variety of funds for innovation in education – the MIT Classes of ’51, ’55, and ’60 funds, for example – and also external funding from The Helena Foundation. I also have a National Science Foundation grant for education from the Division of Undergraduate Education. One of the requirements of that grant is to disseminate this work in learning technology. I’m going to begin doing that dissemination after I teach this course a second time this fall.

Also, it is worth noting that for much of my career I’ve done research for NASA, and I am still actively involved in those programs. My research group is in space plasma physics and we have always had access to professional programmers. There is a synergy here in that a lot of the technology I use for NASA can also help me help my students learn. I also have access to the resources of MIT’s Center for Educational Computing Initiatives (CECI), which has a lot of expertise in developing Java applets and in other technical areas.

The results

The only evaluation I’ve done is to simply ask the students if they like it, and they like it. They like it a lot. Using these visualizations helps them make a robust model for themselves of how things work in electromagnetism, and they can apply that to understanding the material. This fall I’m going to set up a more formal assessment of the technology.

I wouldn't be doing this if it were a 10 percent or even a 50 percent improvement – I just think it's a fundamental improvement in the way you can teach. I don't think it's worth the effort to get into these projects at this level unless you really have a gut feeling that this is really much better.

I'm very privileged. I'm a tenured professor in the Astrophysics Division at MIT; there's a huge amount of astrophysics research going on – science that I'm really interested in. So I'm always waking up in the morning thinking, "Gee, what should I do?" And it's always a choice between very attractive options.

But I also choose to do this work in teaching and learning technology, because I think it's really exciting. There is change floating around – in 20 years science education will be totally different. The question is: How do you get there? And that's what is so interesting.

If you have any questions about the animations, you can contact me at: jwb@space.mit.edu

For an update on my efforts to improve introductory physics at MIT, see: <http://web.mit.edu/jbelcher/www/PhysicsNewsLetter.pdf> (614k).

LINKS
<i>Animations Page:</i> http://web.mit.edu/jbelcher/www/anim.html
<i>View "Magnet Falling through a Ring with Non-zero Resistance" (700k - QuickTime Mov):</i> http://web.mit.edu/course/urop/8.emfields/Public/animations/fall_far.mov
<i>View "Point Charge Attracted to a Charged Sphere" (900k-AVI):</i> http://web.mit.edu/jbelcher/www/att.html
<i>QuickTime:</i> http://www.apple.com/quicktime/
<i>WebAssign - Info:</i> http://www.webassign.net/info/
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