Education News

■ K.C. Gupta

Articles Invited for Education News Column

We invite MTT-S members, RF and microwave educators, and other readers of this magazine to contribute to this column. The objectives of Education News include the presentation of education-related activities of the MTT-S, issues related to education and continuing education of microwave and RF engineers, brief tutorial articles/comments related to RF and microwave educational topics, and technology-aided microwave and RF educational development tools. Please contact Prof. K.C. Gupta (k.c.gupta@ieee.org) with your ideas, proposals, and suggestions for contributions to or comments on Education News.

In this issue, we have an interesting article by Dr. Jim Rautio. Jim was one of the panelists for the panel session on "The Future of Education in the Area of Microwaves" during IMS 2003, held in Philadelphia, Pennsylvania, in June. This brief article entitled "Some Thoughts on Microwave Education" is an extension of the thoughts he shared in panel discussions. Also, in this issue we recognize winners of MTT-S Undergraduate/Pre-graduate Scholarships for 2003–2004 session.

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Some Thoughts on Microwave Education

"Love," is how Bruce Eisenstein described it at the panel session on microwave education at IMS 2003. As with a young man's fancy, we cannot force students to share our love of technology and science in general or of microwaves in particular, but we can provide an environment that will at least give us a chance to share our love if, by chance, it is meant to be.

In spite of having spent several years as a professor long ago, I am not a professional educator. Even so, I was also invited to sit on this panel. Perhaps an outside and unconventional viewpoint was desired. After the panel session, the organizer, K.C. Gupta, asked that I write up some of my ideas. So please feel free to ignore, modify, or even actually use any of my suggestions.

I fell in love with technology as a young boy growing up on a farm. My father, who had not graduated from high school, had somehow put together a ham radio station prior to WWII. I was intensely curious about how the maze of wires, tubes, and equipment worked. Soon, I had a ham license, and in the midst of a period of widespread unemployment among engineers, I decided I wanted to become an "electrical engineer," even though no one in our family had ever gone to college and the financials were daunting. However, farming was now no longer my future.

My route to college was necessarily indirect, but my intense love saw me though various difficulties, eventually yielding a Ph. D. and building a small but successful microwave software company. My suggestions are based on that journey.

First, teach your students about more than just the equations. For example, when teaching Maxwell's equations, point out that Maxwell made two original contributions: displacement current and the creation of a firm mathematical basis for the entire theory of electromagnetics. However, it is often added that Maxwell invented the displacement current term by observing the now obvious symmetry in Maxwell's equations (in fact, this is not the case [1, pp. 90–91]. In addition, as students see the four simple equations that we today call Maxwell's equations, they might think his task was really not all that hard. This is why, whenever I have a chance, I point out that Maxwell himself never saw those four equations. Heaviside and Hertz (who died painfully of blood poisoning after an operation for jaw cancer after a very brief 37 years) later put Maxwell's equations in their modern form independently. Maxwell worked with 20 equations in 20 variables [1, pp. 108–110]. Maxwell did not have the benefit of vector notation, a fact that should cause any student to pause and reflect for a moment.

A few years ago, in exploring the human side of Maxwell's equations, I found myself falling in love with history too. I made a few contacts and obtained a rare book: the 1882 biography of Maxwell [2]. I then spent considerable time scanning some 700 pages. It is on the Internet [3] and has also been independently reprinted [4]. The events of Maxwell's short 48 years (he died of stomach cancer) are amazing and moving. I defy any student of Maxwell's equations to read the brief summary of his biography at [3] and [5] and remain dry eyed.

To make the equations human, occasionally insert an amusing anecdote in your lecture. For example, the following (described by a cousin) from the 1882 Maxwell biography can "brighten up" a lecture on reflection or image theory (for special effect, read it to your class with a Scottish accent!):

> When James was a little boy of two years and a half old, I had given him a new tin plate to play with. It was a bright sunny day; he held it to the sun, and the reflection went round and round the room. He said "Do look, Maggy, and go for papa and mamma." I told them both to come, and as they went in James sent the reflection across their faces. It was delightful to see his papa; he was delighted. He asked him, "What is this you are about, my boy?" He said, "It is the sun, papa; I got it in with the tin plate." His papa told him when he was a little older he would let him see the moon and stars, and so he did."

Another good book for exploring the human side of equations is [6]. For example, rather than just reciting Faraday's Law, you can point out that Michael Faraday as a child was a poor semi-literate street kid and son of a blacksmith put out of work by the industrial revolution. He was apprenticed to a bookbinder, where, excited by the science in the books he was binding, he decided to improve his reading skills. Then, one day, when he was binding a copy of the *Encyclopædia Britannica*, he noticed a 127-page article about electricity. Reading through it, he fell in love with the topic. He was especially enthralled with Galvani's experiments animating dead animals, as his beloved father had just passed away. He imagined, if the room had been dark, seeing the "electric fluid" leave his body when he died. In spite of the fact that people of his class simply could not become scientists, his love for electricity (and some luck) powered him through seemingly impossible difficulties to become one of the most famous scientists of his time.

Faraday's understanding of the universe was incomplete and imperfect. Teach your students that we are no different. For example, a common misperception is that Maxwell's equations are exact and fundamental. In fact, whatever we point to as fundamental is merely the present boundary of our understanding. In the middle of the last century, quantum theory was developed, and we pushed that boundary back, finding that Maxwell's equations fail for a very simple case: low power.

Take, for example, the double slit experiment. At microwave frequencies, we can do this with two dipoles and a power splitter. Maxwell's theory explains the observed interference (antenna) pattern very nicely at high power. But now, reduce the power until only one photon at a time passes through the slits (or antenna). A photon is one quantum of energy and, thus, cannot be split in two. It must pass through one slit or the other, and with no other photon for inference, no interference pattern can possibly form. But pass enough photons, each one by itself, and an interference pattern gradually appears anyway! How can that possibly be? Could the photon actually be passing through both slits? Place a detector on the slits to detect which slit each photon passes through and repeat the experiment. The interference pattern disappears. Each photon somehow knows that it has been seen at the slits and stops interfering. Now we have an opportunity to mention Heisenberg Uncertainty and Schrödinger's cat (which is both dead and alive at the same time), and suggest that the more we know, the more we know we don't know.

The above comes from quantum electrodynamics (QED) as described by Feynman [7], a short easy read I consider required for any student of Maxwell's equations who is otherwise unfamiliar with QED (which includes me). In fact, nearly any book about Feynman is rich with detail useful in adding a human side to the equations we teach.

In Maxwell's time, theory always required a physical basis. For example, Maxwell's work in thermodynamics is based on the highly speculative but very physical concept of "atoms" of different shapes and sizes bouncing around in a box [8]. His early attempts with electromagnetics included a complicated mechanism of gears and wheels to somehow create a medium ("ether") which could propagate a transverse wave with the compete absence of transverse shear strength. Maxwell gave up on this effort, eventually stating that his concept of electric and magnetic fields and potentials was merely an abstract mathematical concept that conveniently allowed calculation of real, observed effects. This jump from mechanical model to pure abstraction was a huge step, opening the way for the supreme abstractness of quantum theory.

Quantum theorists are the first to state [7] that they have no understanding as to why quantum kinds of things happen. All they know is that this theory they have pieced together by trial and error over the years happens to work very, very well. Why it works is simply not known.

We should also teach our students that we do not understand why Maxwell's theory works. I decided to pursue electromagnetics foolishly hoping to answer a childhood question, why a magnet attracts a piece of iron. "Because of the magnetic field," I was told. But I look at the magnet and at the iron and while I feel the attractive force, I see nothing of this "magnetic field" thing. "Can you please put a piece of this magnetic field in my hand?" I ask. "Don't you *believe* in the magnetic field?" my teacher desperately fires back, an odd question for a person of science.

In fact, Maxwell viewed the magnetic vector potential to hold primacy (a view returning to popularity [9]). Heaviside disagreed, treating electric and magnetic fields as the obvious variables of choice. This leads to a paradox, if we were to assume one is actually physical (fields or potentials), the other must be abstract. Which to choose? Perhaps we should hold an election?

The only place I see a magnetic field or vector potential is as a symbol on a sheet a paper, or as a result of a computer's manipulation of many numbers. Both fields and potentials are abstract. Electromagnetics is an empirically developed abstract mathematical theory that happens to model very well the amazing things we see. It answers many quantitative questions, but we must remain humble because it completely fails to answer the single most important question, "Why?"

When I look at a simple magnet attracting a simple piece of iron with the humbling insight that, in spite of all our knowledge and all our equations we still do not know why, it inspires one of my favorite observations: "We are fortunate to have been born into the most incredible universe known to humankind." We should share this sense of wonder with our students; we should not hide it by pretending our equations answer the question why. In fact, that our purely abstract and empirically discovered equations can in some crude way model parts of this universe is itself a part of this wonder.

To provide a comfortable atmosphere for falling in love, we should not start with these dry equations. It is important to start with something "neat." The freshman engineering survey course is a good place. This age group loves to initiate inventive practical jokes. Provide an opportunity for such using microwaves as the means. For example, have the students select a specific TV channel that has a popular show. Build a band stop or a band pass filter (as desired) for just that channel. The students can research the required filter specifications, do the design using CAD software, build it, and then have some fun playing a joke on their fellow students by connecting the filter into the dorm TV feed. Numerous variations on this theme are possible. Give your students the idea that this microwave stuff might actually be worth working with, before they are faced with heavy math.

Most students really like to use computers. There is a lot of free software out there. Most software companies have sweetheart deals for universities; they realize it is a good investment. Use software to the max. Have full versions of software in your lab. Insist that students install free versions on their computers. Can you imagine the feeling a college student gets when she shows her roommate the microwave filter she just designed on her own computer in her own room?

When you do get to the equations, make sure that understanding is primary, the equations themselves are secondary. I recently undertook the difficult task of writing a detailed description of Maxwell's equations for the college-bound high-school senior with some knowledge of calculus. It is on line in the MTT-S section of the IEEE Virtual Museum [10]. Feel free to use this as a starting point. A wealth of additional material is available there.

Finally, help encourage high school students as well. Support your local science museum, both financially and with volunteer time. Support your local science fair. I recently judged at a regional science fair, and I invited several graduate students to go with me. They had an incredible time, and all parties involved benefited. Another important path to encourage high school and middle school students is ham radio. A large number of microwave professionals became interested in microwaves via amateur radio. Encourage amateur radio among your young students. It is an investment that will pay back many times over. It certainly did for me.

Stepping back and looking at a very big picture, starting several years ago and likely to continue into the indefinite future, all people of all countries of the entire civilized world now face mortal attack. This is a war that at any single instant in the next few decades we could all very possibly lose in the fleeting flash of a single millisecond. Our survival as a thriving, prosperous, technologically advanced and freethinking civilization depends on our actively recruiting the young to our cause. We must act now, and with all our energy.

And so, dear professors, dear mentors, and dear lovers all; let's turn the lights down low, play some soft music, prepare a fine dinner, and, with a little luck, we will see if this love is really meant to be.

References

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MTT-S Undergraduate/ Pre-Graduate Scholarships

The MTT-S Undergraduate Scholarship program was instituted in 2000 with the purpose of attracting undergraduate students to the microwave/RF disci-