

# Challenges for electromagnetics teaching and education

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In university-level education in physical sciences and electrical engineering, electromagnetics forms a very important discipline. Courses in field theory are inevitable challenges for students entering these programs. Electromagnetics is often considered a very difficult subject, not only to learn but also to teach. It seems that this attitude is fairly universal. Discussions with colleagues from Europe, America, Asia, and elsewhere confirm the impression that growing to understand electromagnetic fields is not an easy project.

The challenges in electromagnetics education come from different levels. First of all, in classical electromagnetics education, mathematics tools—use of algebra, calculus, and analysis, which are by no means easy topics—are central. However, a plain mastery of mathematical capabilities does not make a sufficient toolbox for the student to cope with Maxwell equations. A conceptual understanding of electric and magnetic fields, charges, currents, potentials, and energy densities has to be developed. One change that has happened in electromagnetics education compared with last century's electrical engineering curricula is the greatly increased emphasis on computation. Students need to become familiar with the numerical and computational aspects of field theory. This challenge is mitigated by the fact that today's students are much more qualified in acting in the digital environment than the older generation electromagnetics faculty. Nowadays young people are at home with Facebook, Twitter, Instagram, WhatsApp, other platforms of social media, and even advanced computer software. And of course, in addition to these challenges, one further expectation in educating students into a mature relation with electromagnetics is that they clearly understand the connection of the electromagnetic concepts to real-world phenomena. Both engineering applications (electrical machines, antennas, waveguiding structures) and natural phenomena (reflection, refraction, and scattering of light, etc.) are governed by the laws encoded in Maxwell equations.

Throughout the past 15 years, I have been organizing sessions about electromagnetics education in various conferences I have been attending in fields of radio science, electromagnetics, and physics. Last year (2013) I arranged the session *Education for electromagnetics* for the *Progress in Electromagnetics Research Symposium* (PIERS) in Stockholm, Sweden [1]. The abstracts and proceedings summaries from that session were duly documented in conference proceedings. But in addition, a special collection of analysis of those contributions was gathered into the *Education* section of FERMAT [2]. Apparently the outcome of this session was positive enough that I was invited to convene as continuation another session on a similar theme for the PIERS meeting in Guangzhou, August 2014 [3].

Having already found a suitable title for the teaching session, "*Education for electromagnetics*", I did not bother to modify the name. With the above background and experiences from Stockholm in mind, I invited several of my colleagues to contribute whom I knew as teaching experts with considerable experience and enthusiasm. I managed to bring together an excellent Focus Session on EM teaching in which we focused on the various aspects of electromagnetics education; all type of electromagnetics teaching related contributions were welcome: case studies of individual courses, good practices in teaching particular physical concepts and phenomena, school and department level views about curriculum design, as well as all EEE (electrical engineering education) research results.

In Guangzhou, our electromagnetics education session was a success: at best moments, close to hundred people joined us in the lecture hall, and all eight [4-11] presentations attracted intense attention and discussion. In a PIERS meeting [1], by definition, participants are experts in electromagnetics research. This is not all: everyone has in addition a deep experience in electromagnetics learning-teaching interaction, all as students (perhaps a long time ago) and very many as teachers, too. Indeed, most of the participants have a long career in electromagnetics educators: lecturing, tutoring, course and curriculum planning, instructing and supervising undergraduate and graduate students. One of the objectives of this session was to make participants appreciate and absorb something from the enormous amount of experience and knowledge of the speakers and neighboring listeners in the hall. Education knowhow can be explicit, and using ordinary communication channels, it can be transmitted to colleagues. However, within the atmosphere in this session, we tried to make open also the silent part of teaching knowledge accumulated in our community.

After the Guangzhou meeting, I invited all speakers of our session to submit their presentation slides and a summary of their talk for this special issue of FERMAT. Eight contributions are posted here.

### **The contributions in the Guangzhou education session**

The presentation slides and commentaries of the presentations in the PIERS 2014 electromagnetics education session are appended in this online FERMAT edition. They hopefully transmit something of the Guangzhou experience of the morning of 26 August 2014.

In the first presentation, Dr. **Stefan Buhmann** from the University of Freiburg, Germany, reported on his experiment to deep-read into the way undergraduate and Master students grasp the phenomenon of light. Using the metaphor *When Light Dawns upon Them*, he charted his students' conceptual understanding of light. (Indeed, the United Nations General Assembly in its 68th Session proclaimed the coming year 2015 as the International Year of Light and Light-based Technologies: IYL 2015 [12]). Buhmann analyzed the structure and morphology of topological maps that the students were able to visualize about their understanding of this concept of light.

Professor **Raj Mitra** (Pennsylvania State University, USA) gave in his presentation *Electromagnetic Education: Is There a Magic Bullet to Fix the Crisis?* his view of the possibilities to attract today's electrical engineering students into appreciation and ability to use electromagnetics in their careers. He emphasized the importance of hands-on course work on the undergraduate level, and a more critical and conceptual approach in the graduate education.

In my own talk (**Ari Sihvola**: *Flux-cutting and Electromotive Force: How to Motivate Students into Electrodynamics*), I reported on my experiences over the last decades of teaching Maxwell equations in the Aalto University School of Electrical Engineering [13]. In particular, I was interested in the manner students grasp Faraday's law, in other words the effect of a time-change in magnetic field into electric force [14]. I reported about my tests on students' understanding of Faraday's law using a two-LED-connected coil and a strong permanent magnet, and also made the same test to the participants in this very PIERS session.

**Lars Jonsson** from the Royal Institute of Technology (Sweden) gave an interesting presentation *Alignment of student activities, through exercises, quizzes, demonstrations, and lectures, applied to electromagnetic teaching*. Students learn by various ways: by hearing, reading, seeing, talking, themselves teaching.... Lars

Jonsson came to emphasize the first word of his presentation title, alignment, in the way electromagnetic teaching would have an effective outcome.

**Jiaran Qi** (Harbin Institute of Technology, China) has experience from both Finnish and Chinese educational systems in electrical engineering. His presentation contained a collection of his own educational tools for facilitating the learning of the most difficult concepts in electromagnetics: electric and magnetic fields, polarization of waves, and waveguides. In addition, Jiaran Qi reported about the various techniques he has been able to secure the attention of students who often risk the anaesthesia from “too many electromagnetic fields”.

A look at the curriculum of electrical engineering from Professor **Daniel Sjöberg** (Lund University, Sweden) gave an interesting viewpoint into the elements that are necessarily required in order to get the educational program accredited by transnational quality assurance systems. In his talk *Using Popular Science Summaries to Improve Writing Skills in Master Theses*, Sjöberg focused on popular summaries that the student has to write as part of the master thesis requirements in order to explicate the contents of her thesis work.

*Practices and Explorations on Introducing New Scientific Research Achievements into Electromagnetics Teaching for Undergraduates* was the title of the talk by Professor **Jing Liu** from the National University of Defense Technology, China. Here we learned about the changes that the Chinese educational system is undergoing. Starting from the outline of *China's National Plan for Medium and Long-term Education Reform and Development (2010–2020)*, Jing Liu listed the requirements that the reform brings about in electromagnetics teaching in the universities in China.

The last talk in our session was entitled *Study of Fraunhofer Diffraction Pattern Using Frequency Image Processing*, and was given by **Jimmy Alexander Cortes** (Universidad Tecnológica de Pereira, Colombia). With South America included, our education session became truly global. As another dimension into the topic of our theme, we learned about the challenges that electromagnetics teachers are struggling with in developing countries. Advanced mathematical computer programs (Matlab, Maple, Mathematica) are not necessarily accessible in everyday life in all countries. We learned about ingenious ways how Colombian universities were using and applying free software to build classroom tools for physics education.

## REFERENCES

- [1] Progress In Electromagnetics Research Symposium (PIERS 2013), Stockholm, Sweden, 12-15 August 2013. <http://www.piers.org/piers2013Stockholm/>
- [2] FERMAT (Forum for Electromagnetic Research Methods and Application Technologies), <http://www.e-fermat.org/>
- [3] Progress In Electromagnetics Research Symposium (PIERS 2014), Guangzhou, China, 25-28 August, 2014. <http://piers.org/piers2014Guangzhou/>
- [4] When 'Light' Dawns upon Them: Mapping the Conceptual Understanding of Electromagnetism Students. Stefan Buhmann (University of Freiburg, Germany).

- [5] Electromagnetic Education: Is There a Magic Bullet to Fix the Crisis? Raj Mitra (The Pennsylvania State University, USA).
- [6] Flux-cutting and Electromotive Force: How to Motivate Students into Electrodynamics. Ari Sihvola (Aalto University School of Electrical Engineering, Finland).
- [7] Alignment of Student Activities, through Exercises, Quizzes, Demonstrations, and Lectures, Applied to Electromagnetic Teaching. B. Lars G. Jonsson (KTH Royal Institute of Technology, Sweden).
- [8] Electrical Engineering Education Systems in Finnish and Chinese Universities. Jiaran Qi (Harbin Institute of Technology, China).
- [9] Using Popular Science Summaries to Improve Writing Skills in Master Theses. Daniel Sjöberg (Lund University, Sweden).
- [10] Practices and Explorations on Introducing New Scientific Research Achievements into Electromagnetics Teaching for Undergraduates. Jing Liu (National University of Defense Technology, China), Jun Zhang (National University of Defense Technology, China), and Hanwu Yang (National University of Defense Technology, China).
- [11] Study of Fraunhofer Diffraction Pattern Using Frequency Image Processing. Jimmy Alexander Cortes Osorio (Universidad Tecnológica de Pereira, Colombia) and Jairo Alberto Mendoza Vargas (Universidad Tecnológica de Pereira, Colombia).
- [12] <http://www.light2015.org/Home.html>
- [13] Aalto University was formed in January 2010 as a merger of three universities: Helsinki University of Technology, Helsinki School of Economics, and the University of Art and Design in Helsinki.