Present challenges and future directions of electromagnetics education

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Electromagnetics and field theory form a fundamental part of electrical engineering education in the university level. The aims and objectives of electromagnetics education are fairly uniform around the international scene: understanding of the physics of electric and magnetic fields, including Maxwell equations, and ability to make use of those results in basic electrical engineering, like circuit elements, transformers, waveguides, antennas, and optical applications. Due to the challenging mathematical basis of electromagnetics and its formulations, a heavy emphasis on differential calculus and vector algebra characterizes everyday teaching of these topics.

In addition to the mathematical prerequisites in learning electromagnetics, the students are faced with demands to develop conceptual understanding of electric and magnetic fields, charges, currents, potentials, and energy densities. This entails a lot of time to be spent with solving problems, both drills of mathematics and homework exercises where an engineering problem has to be seen from the electrophysics perspective and translated into the level of algebraic equations. Also, it is essential that the student grasp the connection of these problems to real-world: in addition to engineering applications also phenomena in nature, like the manner how the polarization of sunlight is affected by reflection from a smooth water surface.

Electromagnetics professors and teachers have been aware of such constraints for the last hundred years. Today, these boundary conditions remain, but the environment is changing. Electromagnetics education needs to respond to today's new challenges. Firstly, our wireless society and dependence on digitally encoded information is in growing need of experts who are capable of dealing with ever more sophisticated radio science applications than before. Secondly, today's young generation is digitally native and prepared to encounter and exploit the distributed data available in the internet, along with the efficient modes of information transmission like Facebook and Twitter. Computerization also has its effect on the methods in teaching of electromagnetics: it is essential that the students become familiar with the numerical and computational aspects of field theory. And the third, emergent, point of view is the focus on new problem-based and student-centered teaching methods in science and engineering which open up wonderful possibilities to engage students into close interaction with professors and fellow learners.

I was called to convene a session on electromagnetics education for the 2013 *Progress in Electromagnetics Research Symposium* (PIERS) in Stockholm in August 2013 [1]. With the above background in mind, I invited several of my colleagues whom I knew had considerable experience and enthusiasm, to contribute. I managed to convene an excellent Focus Session with the title "Education for electromagnetics" 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 Stockholm, our electromagnetics education session was a success: around hundred people squeezed into the lecture hall, and all nine [2-10] presentations attracted intense attention and discussion. In a meeting like PIERS [11], participants are (by definition) experts in electromagnetics research. However, most of the participants have also a long career in teaching electromagnetics: lecturing, tutoring, course and curriculum planning, instructing and supervising undergraduate and graduate students. The session facilitated sharing some of the enormous amount of experience and knowledge, both silent and explicit, that was accumulated in the speakers and listeners present.

After the PIERS meeting, I invited the speakers to submit their presentation slides and a summary of their talk to be included in this special issue of FERMAT. Five contributions are posted here.

The contributions

In the first contribution, Professor **Weng C. Chew** (University of Illinois, USA) takes a global view on the state of electromagnetics education. He has a wide experience on the different educational traditions: the Chinese and Western ones, as well as the British-based curriculum system in Hong Kong which is presently undergoing changes. In his presentation, he draws attention to the decrease of the time students spend on electromagnetics, at least as far as the amount of required courses counts. With some exceptions, it seems that globally the foundations are weakening on which students build their knowhow of field theory. This causes worries about the capabilities of future electromagnetics engineers. It seems that one threat to our profession is the competition from other disciplines: bright students tend to choose more lucrative study directions – like banking and finance – instead of electromagnetics. There are some exceptions: China has a solid production in education: around 600 000 engineers per year. Also it is indicative that in Hong Kong, the quality students come from Mainland China. Professor Chew is searching for optimism to the future of electromagnetics from multidisciplinary areas: in electromagnetics education and research, we should focus on emerging fields like nanotechnology, quantum electromagnetics, optoelectronics, bio-electromagnetics, etc.

Professor **Rajeev Bansal** (University of Connecticut, USA) looks into the topic from the point of view of motivating all students in the classroom. We need to admit that most of the students taking the basic field theory course will not later pursue a career in electromagnetics. Hence, rather than offering an exhaustive and mathematically challenging treatment of electric and magnetic fields, it would be more useful to develop a teaching method that motivates all students, is an appetizer to many of them towards advanced studies, connects electromagnetics into broader context, and still conveys some of the physical and mathematical principles that from the foundation. Inspired by the recent book *Networked Life: 20 Questions and Answers* (Cambridge University Press, 2012) by Mung Tiang at Princeton University, Professor Bansal suggests a "Just-in-Time" teaching principle. Starting by a question which is connected to everyday life and electrical engineering (for example, "Can my iPhone cause cancer?"), a short answer is first looked for with qualitative justifications. Then, while searching for a long and more definitive answer, the problem is approached from a more theoretical perspective and with amount of mathematics that is "just-enough". It is essential to find questions that matter.

In the presentation *Computer-aided Teaching of Electromagnetics: Is It for Real?*, Professor **Raj Mittra** (Pennsylvania State University, USA) emphasizes the need for a paradigm shift in electromagnetics education. We all know that field theory is hard to grasp and takes a long time to get familiar with. Vector calculus is needed, as well as differential equations, and complex algebra. On the other hand, computers have changed the teaching environment by not only their enormous calculational capabilities but also by the fact that the young generation is digi-friendly, and hence there exists unanticipated potential for the use of computers and internet in the learning environment. In this new setting where numerical software can rapidly provide students solutions for electric and magnetic field distributions in complex structures and also visualize the solution efficiently, the challenge is to secure students' conceptual understanding and their ability to judge whether the results of the computations are to be trusted. Professor Mittra illustrates these issues with examples from waveguides, patch antennas, and metamaterials.

Professor **Daniel Sjöberg** (Lund University, Sweden) reports on electromagnetics teaching from a more didactical point of view. He has been experimenting with web quizzes that complement the classroom teaching and homework problems. Using *Moodle*, an open-source software for learning environments, small-scale problems are assigned weekly to test the conceptual understanding of the students. The work load of a single quiz is of the level that the time that the students spend on it ranges from minutes to a couple of hours. The feedback tells that the students appreciate the quiz system and feel that it supports their learning. Of course, a challenge is to design suitable quizzes and problems which match smoothly the moodle platform and are interpreted unambiguously by the students. However, the automated grading of the quizzes makes the system very appealing for use in connection to courses with a large number of students.

The fifth contribution comes for Aalto University, Finland. Dr. **Kirsti Keltikangas** and Professor **Keijo Nikoskinen** describe a curriculum reform launched in the Fall term of 2013 in Aalto University. Aalto University in Finland is a merger (in 2010) of three universities with a long history: Helsinki University of Technology (TKK), Helsinki School of Economics, and the University of Arts and Design. In addition to heavy organizational reforms, Aalto is also in the middle of changes of teaching structures. The so-called Bologna process [11] involves European–Union level agreements which aim to unify and homogenize the higher education qualifications in European countries and facilitate mobility between universities. This has required curriculum reforms in many countries. For example in the Finnish pre-Bologna system, engineering universities did not offer any bachelor degrees. The five-and-a-half year program led directly to the degree of "diplomi-insinööri". The bachelor degree programs were incorporated in 2005, and presently the second wave of curriculum reform is underway. Dr. Keltikangas and Professor Nikoskinen describe the contents of this transform from the electrical engineering perspective, including its objectives to increase cross-disciplinary elements and new pedagogical teaching styles into education.

REFERENCES

[1] Progress In Electromagnetics Research Symposium (PIERS 2013), Stockholm, Sweden, 12-15 August, 2013. http://www.jorcep.org/piers2013/

[2] Comparing Electromagnetics Education in China, Hong Kong, and USA. Weng Cho Chew (University of Illinois, USA), Li Jun Jiang (The University of Hong Kong, China), Wen Xun Zhang (Southeast University, China), Xin-Qing Sheng (Beijing Institute of Technology, China), and Jin Pan (University of Electronic Science and Technology of China, China).

[3] Just in Time: Teaching Electromagnetics in the 21st Century. Rajeev Bansal (University of Connecticut, USA).

[4] Electromagnetics Basic Courses: A Student-activating Approach. Jari J. Hänninen (Aalto University School of Electrical Engineering, Finland).

[5] Computer-aided Teaching of Electromagnetics: Is It for Real? Raj Mittra (The Pennsylvania State University, USA).

[6] Using Web Quizzes to Assess Concept Understanding and Pacing the Students. Daniel Sjoberg (Lund University, Sweden).

[7] Impact of Counselling Programs on the Academic Results at Telecommunication Engineering Degree. M. Edita De Lorenzo Rodriguez (Universidad de Vigo, Spain), Artemio Mojón (Universidade de Vigo, Spain), Generosa F. Manín (Universidade de Vigo, Spain), Cristina L. Bravo (Universidade de Vigo, Spain), and Inigo Cuinas (University of Vigo, Spain).

[8] Challenges in Electromagnetics Education Design as a Part of Curriculum Reform Process. Kirsti Keltikangas (Aalto University, Finland) and Keijo Nikoskinen (Aalto University, Finland).

[9] Understanding Matching Circuits; Plastic Made Quasioptical Multilayer Matching Unit Design at X-band. Tugrul Aydogmus (Akdeniz University, Turkey), İnan Kopcal (Akdeniz University, Turkey), Gizem Kahya (Akdeniz University, Turkey), Yalçın Albayrak (Akdeniz University, Turkey), Selcuk Helhel (Akdeniz University, Turkey), and Sukru Ozen (Akdeniz University, Turkey).

[10] Virtual Laboratory for Microwave Devices. D. S. Gubsky (Southern Federal University, Russia), I. V. Mamay (Southern Federal University, Russia), and Viacheslav V. Zemlyakov (Southern Federal University, Russia).

[11] Bologna process. http://en.wikipedia.org/wiki/Bologna_Process

Ari Sihvola was born in 1957, in Valkeala (Finland). He received the degrees of Diploma Engineer in 1981, Licentiate of Technology in 1984, and Doctor of Technology in 1987, all in Electrical Engineering, from the Helsinki University of Technology (TKK), Finland.

Besides working for TKK and the Academy of Finland, he was visiting engineer in the Research Laboratory of Electronics of the Massachusetts Institute of Technology, Cambridge (USA), in 1985–1986, and in 1990–1991, he worked as a visiting scientist at the Pennsylvania State University, State College. In 1996, he was visiting scientist at the Lund University, Sweden, and for the academic year 2000–2001 he was visiting professor at the Electromagnetics and Acoustics Laboratory of the Swiss Federal Institute of Technology, Lausanne. In the Summer of 2008, he was visiting professor at the University of Paris XI, France.

Ari Sihvola is professor of electromagnetics in Aalto University School of Electrical Engineering (Aalto University was created in 2010 as a merger of three universities: Helsinki University of Technology, Helsinki School of Economics, and the University of Art and Design). His scientific interests range from electromagnetic theory, complex media, materials modeling, remote sensing, and radar applications, into engineering education research and history engineering and technology.

Ari Sihvola is Chairman of the Finnish National Committee of URSI (International Union of Radio Science), Vice Chairman of the Commission B (Fields and Waves) of the international URSI, and Fellow of IEEE. In 1990's, he has served as Chairman of the IEEE AP–MTT Chapter for several years. He was awarded the five-year Finnish Academy Professor position in 2005–2010. During 2008–2013, he served as director of the Finnish Graduate School of Electronics, Telecommunications, and Automation (GETA). Author of several books and hundreds of publications, Ari has been active in organizing conferences and workshops, convening and chairing sessions, and serving in advisory, technical, and organizing committees for numerous national and international scientific symposia as member, secretary, or chairman. In TKK and Aalto University, Ari Sihvola has received several teaching awards, like the "Teacher of the Year" Prize in 1995 from the Student Union of TKK.