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Adventures in Contemporary Electromagnetic Theory

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Chapter 22
Theoretical Future: Vision 2030

Amir Boag, Vadim A. Markel, Olivier J. F. Martin, M. Pinar Mengüç, and Kevin Vynck

A round table discussion on the topic "Theoretical future—Vision 2030" was organized during the Weiglhofer Symposium on Electromagnetic Theory. The panel included Amir Boag from Tel Aviv University, Vadim A. Markel from the University of Pennsylvania, M. Pinar Mengüç from Ozyegin University, and Kevin Vynck from the University of Lyon, and it was chaired by Olivier J.F. Martin from the Swiss Federal Institute of Technology in Lausanne (EPFL). All participants to the symposium contributed actively to the discussion (Fig. 22.1).

With their opening statements, the panelists emphasized the key role that Maxwell's equations are playing in our society today. Electromagnetism is the driver behind so many indispensable technologies: from automotive to imaging, from telecommunications to remote sensing, from electronics to energy harvesting, with application frequencies that cover at least fifteen orders of magnitude.

Industrial cycles are becoming shorter as the time between an initial idea and its application in a product is shrinking. This calls for novel design approaches, possibly beginning from materials and their functions, then their characterization and integration into a complete system—metamaterials represent a good example where this approach is quite successful.

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Fig. 22.1 The panelists (from left to right): A. Boag, V. A. Markel, M.P. Mengüç, K. Vynck, and O.J.F. Martin (photo P.B. Monk)

The rapid acceleration that we have witnessed over the last couple of decades in the utilization of Maxwell's equations also brings about novel societal responsibilities. With the Internet of Things, the number of radiators in a room is increasing at a rapid pace and one may wonder whether all that connectivity is really needed, a societal debate that extends much beyond electromagnetics. The influence of electromagnetic fields on humans and animals is also a topic that requires multifaceted competences and should be investigated considering not only possible adverse effects but also potential electricity-enabled medical treatments.

Many technologies based on electromagnetics are quite energy-greedy and we should endeavor that our research does not hurt the environment and be always aware of its impact, including the gray energy it generates. At the same time, it was eloquently explained that electromagnetics also bears the cure against some of its excesses and research topics like radiative heat transfer, thermal radiation, or passive cooling fall perfectly within the realm of Maxwell's equations. Overall, inspiration from the natural world can help us address some of those challenges.

Although computational electromagnetics is a very mature field of research, there are still quite a few challenges that cannot be solved with commercial programs. These include complex, multiscale, three-dimensional geometries, or systems with internal resonances, which remain difficult to handle. Large disordered systems as found in nature are also beyond the current state of the art. Sometimes, the numerical approaches are excessive in what they produce and it would be efficient to limit calculations to what is really needed, e.g., the scattering cross section or the optical force acting on an object. Additional research efforts should be invested into direct solvers and irregular grids. Multiphysics approaches are becoming increasingly important and so are techniques that can bridge the gap between classical electromagnetics and quantum systems, although they are still in their infancy. Machine learning has certainly emerged as a very popular approach, and one should attempt to seamlessly integrate Maxwell's equations into those new techniques, rather than applying them by brute force. Some participants emphasized also that some mathematical tools, like the complete characterization of an algebraic variety, are essential to gain insights in the response of complex electromagnetic systems, like three-dimensional photonic crystals.

The panel was unanimous to note that the widespread availability of commercial and free software for the solution of Maxwell's equations is a mixed blessing. On the one side, it supports the central position of electromagnetics in many modern technologies and allows facile simulations to illustrate many physical situations. On the other side, there are numerous pitfalls in the utilization of these commercial and free software it seems that a significant portion of the user community is satisfied with a colorful image of the field distribution and rarely question the validity of their numerical results or carefully check the convergence of their simulation.

This observation echoes a topic that emerged strongly in the course of the discussion: how to educate students in electromagnetics? The panel noted that good students interested in that subject are difficult to find. Some panelists regretted that this field of study had shifted from the physics departments to electrical engineering departments. There was also a consensus that electromagnetics is taught in a rather old-fashioned way, with "modern" textbooks merely duplicating previous works.

All participants to the symposium shared a vivid enthusiasm for Maxwell's equations and the amazing construction he established over 150 years ago. There was a general feeling that this enthusiasm should be better conveyed to students and used to tease their intellectual curiosity and inspire them. Some disruptive approaches to diversify teaching were also proposed, like replacing the seemingly complicated vector calculus with matrices and numerical calculations or using graphical examples to visualize abstract concepts: showing, for example, to the students what the nabla operator does to the electric field.

The ubiquity of Maxwell's equations in today's technology suggests that Centers might be more appropriate for electromagnetics research than Departments. This proposition lends itself well to more inter- and multi-disciplinary approaches, where teams of students from different backgrounds work together on a specific project. There was however a call for caution with interdisciplinary projects introduced too early in the curriculum, which boils down to the least common multiple of available competences. It is essential that students master their own discipline well, before contributing meaningfully to a complex, multifaceted project. Yet, learning to communicate, collaborate, and work in a team are also key assets that need to be practiced.

Although not specific to electromagnetics, it was noted that scientific integrity and awareness of the societal impact of technology should be prominent throughout the entire curriculum. Finally, the participants wished for a better gender balance in hard sciences at large and electromagnetics in particular.