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Educating Students on Metamaterials – The Story of the EUProMeta

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Abstract—The EUProMeta is an international distributed doctoral school that educates students at the Ph.D. level in all theoretical and experimental aspects of metamaterials. This contribution provides an overview to the activities of the school, its intention, its structure and the way individual school events are implemented. The article aims to raise awareness that education of students is an essential ingredient of a research community that advances its research field as a whole. Doctoral schools are an excellent institution to set a base of shared knowledge in a community and to interlink the people that contribute most to the actual research performed in the field.

I. INTRODUCTION

The EUProMeta is an abbreviation which stands for European Doctoral Programmes on Metamaterials [1]. At its heart it is devoted to the education of students in all aspects associated to the field of electromagnetic metamaterials and related fields of science and technology. As a short introduction to the context, it has to be said that metamaterials consist of structures with feature sizes in the order of magnitude or much smaller than the wavelength [2], [3], [4]. They can be designed to operate at every possible frequency of the electromagnetic spectrum. It is common sense to understand them as materials that allow to observe a response unattainable with natural materials. They have triggered our imagination by enabling applications that differ from our daily perception of how electromagnetic fields propagate in space and interact with matter.

The work in this field is characterized as being extremely inter-disciplinary. It requires a profound expertise in many

fields of science and highly developed engineering skills that necessitate training in many different disciplines. This possesses quite a challenge in education, since this field of research unifies many different aspects and approaches. The properties of metamaterials can be described in many different scientific languages that are reminiscent to the different spectral ranges in which metamaterials are explored. Since metamaterials do present considerable intellectual challenges in diverse areas of research, it has become evident that a single educational institution is no longer in position to provide an adequate education to post-graduate and master students in a comprehensive and sound manner. Only synergy and joint efforts of the leading experts in Europe and from the rest of the world allow nowadays to provide such education.

It is the purpose and the intention of the EUProMeta to address these requirements. At its heart it educates students in all subjects related to metamaterials. This paper provides a short introduction to the school, its historical roots, the way it is structured, but also to some challenges and problems we, the people behind the school, do face.

II. HISTORICAL NOTES

The EUProMeta was established on April 15, 2005 by the Metamorphose Virtual Institute (VI), and its first organizer was Dr Filippo Capolino, at that time working in the University of Siena in Italy. The Metamorphose VI was founded by the European Network of Excellence (NoE) *Metamorphose* (METAMaterials Organised for radio, millimetre wave, and

PHOTonic Superlattice Engineering). This NoE was funded in the 6th Framework Program of the European Commission and united more than 25 universities and research institutions all across Europe in their joint research on many research topics associated to metamaterials. The Metamorphose VI supports the organization of the EUProMeta. The school operation is governed by a memorandum of understanding that has been signed by all partners. It is accompanied by a set of internal regulations that contain practical and specific information concerning the implementation of the school.

III. STRUCTURE OF THE ENTIRE PROGRAM

Although the EUProMeta focuses on the organization of a series of short courses, the entire program is more than just a collection of individual school events. After completing the courses and collecting the required number of credits, the school attendees can be entitled for a special certificate called the *Mention of Excellence in Metamaterials*. To be eligible for receiving this certificate, which can be issued upon request in addition to the regular Ph.D. degree, the students have to provide evidence that they have successfully met a series of requirements. Most notably the students are required to:

- 1) obtain at least 5 credits from different school events,
- 2) publish at least one journal publication in the field of metamaterials jointly authored with researchers from another institution participating into the program,
- 3) publish at least one more journal publication in the field of metamaterials not necessarily jointly authored with researchers from another institution participating in the program,
- 4) have at least three conference publications in the field of metamaterials,
- 5) submit a Ph.D. thesis in the field of metamaterials and
- 6) spend at least 3 months in total conducting metamaterials research in the laboratories of another research institution that is not the home institution.

As it can be already seen from this short list of requirements, the purpose of the school is not limited to pure education, but also to foster the student mobility between the partners and to generate an atmosphere of mutual understanding where joint efforts lead towards the accomplishment of a common scientific goal. The EUProMeta has its greatest impact, however, through organizing different school events. The school events provide the ideal playground to initiate joint research, in addition to the annual conference *Metamaterials* organized by the Metamorphose VI.

IV. STRUCTURE OF THE COURSE PROGRAM

The course program of the EUProMeta consists of a set of regular school events covering well defined topics and which are delivered at a fixed frequency. The frequency orients on the average time a student will spend on working towards her/his Ph.D. degree. Namely, most of these core courses are given twice within six years. These core schools are delivered under a certain theme and presently we have identified six of such themes. They deal with the following topics:

- 1) An Introduction to Metamaterials
- 2) The Fabrication of Metamaterials
- 3) The Characterization of Metamaterials
- 4) Effects to be observed in Metamaterials and the Underlying Physics
- 5) Optical Metamaterials
- 6) Microwave Metamaterials

In each of these core schools a set of three to four main lectures that are understood as essential are delivered, and this constitutes the key element of each core school. These main courses are supplemented by more specialized lectures that are delivered by selected lecturers from the partner organizations or by the experts in the particular field already attending the school event or the qualified host researchers. The pool of planned lectures is frequently adjusted to reflect the current stream of research interests and activities in the field of metamaterials.

This set of core short courses is complemented by a series of ad hoc organized school events on more focused subjects. They may cover such specific subjects as, e.g. nonlinear metamaterials, computational techniques to simulate the properties of metamaterials, tunable metamaterials, or other topics with a similarly deep focus. Some of these additional schools are collocated with the annual Metamaterials Congress of the Metamorphose VI that usually takes place in the autumn of each year. The advantage of combining a school to such large conference is obviously two-fold. On the one hand, a sufficiently large number of experts is present at the site to deliver lectures on various aspects of the same subjects. And on the other hand, the majority of Ph.D. students that do research on metamaterials equally come to the conference to present their latest result.

Overall, more than 20 EUProMeta school events have been organized so far. In the average two to three schools are organized in each year and they are geographically distributed all across Europe. It is the natural goal to extent collaboration and the organization of schools with comparable institutions world wide; and this presentation is aimed to help to promote such cooperation.

V. STRUCTURE OF A SCHOOL EVENT

The school event duration may vary between two (schools usually collocated with the conference) and five days (schools of the core set or other schools focused on a specific topic of current interest). Their local organization is carried out by an assigned host institution which usually takes responsibility on all the aspects of implementing an individual school. In general, it is preferred that at least for the schools that belong to the core set, the schools are organized on a regular basis by the same partner. This is done with the purpose to standardize the efforts and the requirements and to ensure in the long term the same high quality of lectures that are delivered to different cohorts of students. Moreover, obviously it simplifies the organization if the procedures do not need to be reinvented every time. In practice, this implementation scheme appears to a certain extent problematic and for various reasons cannot

be strictly maintained. On the one hand, people who are deeply involved in the organization of the school may simply change their working place as a part of the regular flow of their academic lives. Also, other obligations might prevent the organizer of a school event to take responsibility for the event in a particular year that has been scheduled at his/her site. For all these aspects it has to be kept in mind that all activities concerning the organization of the school take place strictly on a voluntary basis with no additional compensations.

The school events include lectures, seminars and exercises where the students have to solve assigned tasks to deepen the understanding of the contents of the lectures, visits to labs working in the field of metamaterials at the site of the school and, of course, a blend of different social activities. They comprise organized tours to touristic destinations and attractive sites, and a traditional get-together school dinner (see on Fig. 1 how lucky students can look like on a group picture). Additionally, a poster session can be organized where the students also get the opportunity to present results from their research to other participants and experts teaching at the school. Such sessions turned out to be in the past extremely useful to initiate the discussions among the students.

Fig. 1. Lucky students at a school that took place in Siena, Italy 2011

Eventually, the school event may be finished with an examination that can be a written test or an assignment. The latter usually consists of an essay or a small discussion of a particular aspect of metamaterials that has been dealt with in the lectures of the school. These assignments can be also submitted after the school. They will be marked by the local school organizers when the assignments have been sent to them. In terms of ECTS credits these schools count up to three credits. Five-day schools with no final assignment can count up to one-and-a-half ECTS credits. These ECTS credits can contribute towards the final certificate *Mention of Excellence in Metamaterials*, and they can also be accepted by the home institutions as credits in fulfilment of the requirements to the PhD degree.

VI. FINANCIAL ASPECTS

Having described now the majority of aspects of the school operation and organisation, it is worthwhile to mention certain

problems and challenges the school is facing. The first one is related to the financial sustainability. The school budget is entirely dependent on the registration fees paid by the attendees. These fees typically cover the costs of the venue, lunches and the school dinner. Sometimes, the travel expenses of the invited lectures are partially covered. Additionally, up to three travel grants are awarded to students who should apply in advance. These travel grants are topped up by the registration fee waivers. They shall be granted, most notably but not exclusively, to students from the low-income countries. Although the budget of each individual school event can usually be balanced, no resources exist that would contribute to building-up a risk reserve. Therefore, total financial reliance on the registration fees represents permanent risk for the school future. Moreover, the European focus of the school and the organisational structure that is exclusively based on volunteers, create operational difficulties aggravated by the total lack of the relevant funding schemes.

VII. CONCLUSIONS

EUProMeta is operated essentially by a large number of passionate people all around Europe and the World. They are pleased to see that there is always a new generation of students that are fascinated about metamaterials. Educating these students makes it after all a lot of fun and personally rewarding. The authors believe that new ideas for novel research streams are created in the course of lively discussions between students and experts at the school events. It is the philosophy and the intention of the EUProMeta to generate exactly such creative atmosphere where people meet and discuss on a research subject they admire.

More information on the activities of the EUProMeta can be found on the web at <http://school.metamorphose-vi.org/>. More information on the activities of the Metamorphose VI can be found on the web at <http://www.metamorphose-vi.org/>.

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