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Horizons in Physics Education

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Executive Summary

HOPE (Horizons in Physics Education) brought together 71 partners including 65 university physics departments, CERN, 4 associations (the European Physical Society, the Italian Physical Society, the International Association of Physics Students and the Italian Association of Physics Teachers) and a private business from 31 Lifelong Learning Programme (LLP)-eligible countries. The network was further enriched by the inclusion of 20 associated partners from Europe, North and South America and India. Its ultimate goal was to enhance the impact of physics and its visibility in society in general by increasing the number of physics graduates.

HOPE has focused on four major complementary themes that taken together represent physics education of students from school to graduation:

i. Inspiration of young people to study physics,
ii. Physics graduates' competences, particularly for innovation and entrepreneurship,
iii. Global competitiveness of Europe's physics courses,
iv. Strategies for improving the supply and training of physics teachers.

The themes in this project are timely for most European countries and were developed by a consortium with experience of similar sized networks in the past. The activities, including exploitation and dissemination, were executed by four Working Groups (WG) and all activities have been evaluated and validated by recognized experts. The HOPE web-site (**www.hopenetwork.eu**) facilitated the collaborative work within the network and enhanced considerably its visibility to target groups; it provides a continuous and long term way of disseminating the project's activities and principal results, serving not only the project partners but the whole physics community in EU countries.

In terms of outputs, recommendations have been made and concrete strategies offered. The outcomes of the project are meant for all higher education institutions providing physics degrees, academics, physics teachers and students in Europe, as well as organisations and national and local governments which have a role in education in physics and pre-university physics learning.

Three annual Forums with topics focused on the WGs' lines of action took place in three different EU locations: Helsinki, FI (2014), Coimbra, PT (2015) and Constanta, RO (2016). These included invited and contributed oral presentations, poster sessions and Round Table discussions aimed at disseminating best practice in EU universities/countries. All forums were successful events with large participations from HOPE partners, associated partners, students and professional bodies. The project has been publicized (articles in journals and newsletters) and discussed in several national and international meetings by many members of the consortium.

The final project results, particularly the conclusions and recommendations, represent the most important dissemination material and will be presented in a comprehensive Booklet, "Horizons in Physics Education", for distribution throughout EU countries, to educational decision makers, including university leaders and national and local government bodies, to European Physical Society (EPS) and national physics associations, to central EC agencies and other academic networks and LLP projects, to students and physics teachers associations.

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1. Project Objectives

HOPE's goal as declared in the application was to enhance the impact of physics on the European economy and its visibility in society. This would be done by various investigations leading to conclusions and recommendations to stakeholders such as the physics departments in partner universities and the European Higher Education Area, the physics community within the EU, national and European physics societies, organisations connected with the training of physics teachers for schools and national or local government departments responsible for school curricula.

The project's goal was pursued via objectives represented by four interlinked and complementary major themes which in turn formed the basis of the work programmes of the four Work Groups (WG).

WG1. *Inspiring Young People to Study Physics*:

"To investigate the factors that influence young people to choose to study physics."

WG2. *New Competences for Physics Graduates – Fostering Innovation and Entrepreneurship*:

"To recommend ways by which physics degrees can be enhanced so that the competences of graduates enable them to contribute more effectively to Europe's economy and society, particularly through innovation and entrepreneurship."

WG3. *Improvements in Physics Teaching – Meeting Future Global Challenges in Physics Higher Education*:

"To improve the effectiveness and attractiveness of physics teaching in Europe's university physics departments to help ensure their competitiveness in the global student market."

WG4. *Improvements in the Training and Supply of Physics School Teachers*:

"To recommend strategies for increasing the supply of well-trained physics school teachers and to enhance the role of university physics departments in helping the teaching of physics in schools."

A working plan with 11 work packages was put in practice and specific objectives were stated. The most important have been:

- to develop and exploit activities, in parallel within each workgroup, but addressing and involving all the project partners,
- to develop HOPE's web-site as a tool for project management, dissemination of results, and the enhancement of the project's visibility to serve not only the project partners, but also the whole physics community in European countries.
- to organize three Annual Forums, each one focusing on one or two of the major themes along with updates from the other themes, and representing the principal way for dissemination of results obtained by the working groups,
- to develop recommendations after a large consultation of partners,
- to enhance the involvement of physics students and physics high school teachers in project activities, via their professional national and European associations,
- to obtain feed-back from principal stakeholders and to offer examples of good practice,
- to enhance the awareness of society (employers, pupils, public bodies) as regarding the competences of physics graduates in a knowledge based society.

2. Project Approach

GOVERNANCE

HOPE was managed by a Management Committee (MC) comprising the applicant and two other partners. The MC had overall responsibility and supervised the project's activities. It was assisted by (a) an Advisory Board (AB) of six experienced partners (reduced to 5 in 2014 after the sudden death of one member), and (b) the leaders of the four Work Groups (WG). The AB gave guidance and ensured internal evaluation, while for external evaluation, experts outside of the network were employed; Work Package 2 (Monitoring and Validation) defines the Quality Assurance tasks, actions and dates.

The MC met regularly by Skype, with formal combined meetings of MC, AB and the WG leaders being held at the WG meetings. In addition, longer (2 days) management meetings have been held in the autumns of 2013 and 2014 and early 2016. The agenda for meetings included discussion of overall progress, the financial situation, and detailed reports from the WG leaders.

METHODOLOGY

HOPE's researches were conducted by four Work Groups (WG) each concentrating on one of the project's four themes as described in *Section 1: Project Objectives*. The 71 full partners from 31 LLP-eligible countries were distributed among the four WGs with most partners being members of two or three according to their academic interests. The activities of the four WGs were organised in parallel but with a phased start. This has the advantage of spreading throughout the year the demands made of partners and allowing the Annual Forums (see below) to focus on one or two well defined themes.

The procedures adopted by the WGs differ in detail but involved the use of questionnaires circulated to partners, students, alumni, employers and school teachers as appropriate. Other investigations used information collected from non-partner universities. The network partners had already wide experience in enquiring, analysing, and disseminating results, most of them being beneficiaries of long term fruitful co-operations. For each WG, two work packages were defined: (i) implementation (i.e. the performance of the WG's activities, and (ii) exploitation of results.

Each WG leader, assisted by a co-leader, developed and coordinated the WG's programme necessary to achieve its outcomes, based on the activities performed and the decisions reached at the WG's two meetings. The first of the two meetings was to brainstorm and set targets, whereas by the second, sufficient work even of a trial nature had usually been done for progress to be reviewed and final goals established. The attendance and participation of relevant target decision makers from universities, industry, national physical societies and other appropriate associations helped inspire partners with their contributions. Meetings of WGs evolved into a format of commencing with lunch on the Thursday and finishing with lunch on the Saturday thus also including two evenings for informal discussions and networking.

The Annual Forums held at the end of each year of the project were the most important events in HOPE. At least one representative of each partner institution was invited with full support but the Forums were also attended by additional partner representatives, associated partners, teachers and students via alternative funding packages. One or two WGs organised the forum with the emphasis of the programme reflecting their objectives. WG leaders and members made comprehensive presentations on their results, outcomes and recommendations; meanwhile, the leaders of the other WGs gave presentations on progress achieved to date or from the previous Forum. The Forums' programmes also included keynote talks by invited speakers on appropriate subjects, oral and poster presentations by members of HOPE, and Round Table discussions to explore these issues in detail. This pattern ensured that WGs were focused on their tasks as their milestones were regularly reviewed and open for comment and criticism by all partners, and it additionally helped to maximise the involvement of partners.

The final project results and particularly the conclusions and recommendations are considered as representing the most important material for dissemination. Many have already been disseminated via invited and contributed presentations at international conferences and as papers or draft papers in peer-reviewed journals. A comprehensive electronic booklet presents the main achievements, results and recommendations of the project for distribution to the relevant target groups throughout EU countries.

3. Project Outcomes & Results

INTRODUCTION

The major outcomes of the project are made public by HOPE's web site (**www.hopenetwork.eu**). The complete web-site started in late 2014 and was used as a dynamic tool for communication with partners, for networking and for the dissemination of results and useful information. The development of the web site depositories was strongly correlated with the progress of the activities.

The HOPE consortium brought together university partners from 31 Lifelong Learning Programme **(**LLP)-eligible to strengthen European links and dialogue within the discipline of physics and physics connected areas. Eight Work Group (WG) meetings, three annual Forums and also 7 small meetings of key members for planning and analysis were organized. Most of the partners (69 from the total of 71) were represented by one or more staff persons to at least one of the organized events (WG meetings and Forums).

The 21 associated partners from EU and non-EU countries joining the HOPE consortium have been represented at these events by 12 participations. Students representing IAPS (International Association of Physics Students) - a full partner of HOPE - contributed by a very active involvement in all project activities including membership of subgroups at WG meetings discussing aims and questionnaire design, and participation in Round Tables and the presentation of posters at the annual Forums.

ANNUAL FORUMS

The most important events of the project were the three annual Forums where the principal results and outcomes of the project were presented.

The **first Forum**, "INSPIRING YOUNG PEOPLE TO STUDY PHYSICS", was held in Helsinki, Finland in August 2014 and had a large audience of 97 participants, representing 60 partners, 5 associated partners, 13 external attendees and 5 students. It was mainly prepared by WG1 (Inspiring Young People to Study Physics):and locally organized by a committee from the University of Helsinki. The programme of this Forum and the two subsequent ones was designed to involve as many partners as possible; hence, WG and subgroup leaders gave updates and results on their investigations, partners delivered contributed papers linked to the themes of the Forums and participated in Round Table discussions, while others presented posters.

In addition to reports from WG1 (which had been carrying out its work since January 2014) and introductions to WG2, WG3 and WG4, the Forum's main themes were:

- Inspiring the young
- From school to university
- Promoting physics

The forum included a poster session of 36 presentations by participants from partners and associated partners and by students.

The invited speakers were selected to introduce the themes and complement and stimulate the related presentations by other attendees.

- Pekka E. Hirvonen, University of Eastern Finland, Finland: LUMA-Suomi programme.

- ❖ Peter Main, Institute of Physics, UK: Increasing the number of physicists - breaking the vicious circle.
- ❖ Rolf Hempelmann, Saarlands University, Germany: German Schülerlabor - Development, position today and impact.
- ❖ Paula Heron, University of Washington, USA: Broadening participation and deepening engagement:

The programme was completed by two Round Table discussions - “Inspiring the young” and “University outreach and widening participation” - and a Finnish pop-up science theatre show - “Pop-up Heureka”.

The **second Forum**, “PHYSICS STUDIES IN AN ENTREPRENEURIAL AND INNOVATIVE GLOBAL PERSPECTIVE”, was held in Coimbra., Portugal in September 2015 and had a large audience of 90 participants, representing 55 partners, 1 associated partner, 10 students and 7 external attendees. It was prepared jointly by WG2 (New Competences for Physics Graduates – Fostering Innovation and Entrepreneurship) and WG3 (Improvements in Physics Teaching – Meeting Future Global Challenges in Physics Higher Education) and was locally organized by a committee from the University of Coimbra.

In addition to reports from WG2 and WG3 and updates from WG1 and WG4, the Forum’s main themes were:

- ➢ Physics studies in an entrepreneurial perspective
- ➢ Physics studies in a global perspective

The forum included two poster sessions of 34 presentations by participants from partners and associated partners and by students.

Again the invited speakers were selected to introduce the themes and complement and stimulate the related presentations by other attendees.

- ❖ Paulo Pereira da Silva, CEO, Renova, Portugal: Confessions of a physicist in the real world.
- ❖ Jim Allen, Research Centre for Education and Labour Market, University of Maastricht, The Netherlands: Skills for the future: challenges for higher education.
- ❖ Dorothy Kelly, University of Granada, Spain: Internationalization: why is it a good thing ?

The programme was completed by two Round Table discussions - “Where should students acquire professional and entrepreneurial skills - at university or in employment?” and “Innovative teaching methods”.

The **third and final Forum**, “PHYISCS TEACHING IN EUROPE AND HOPE IN PERSPECTIVE”, was held in Constanta, Romania in September 2016 and was attended by 82 participants, representing 56 partners, 10 students and 9 external attendees. It was prepared by WG4 (Improvements in the Training and Supply of Physics School Teachers) and WG3 (Improvements in Physics Teaching – Meeting Future Global Challenges in Physics Higher Education) and was locally organized by a committee from the University of Bucharest.

Although the programme focused on WG4, it also included the final results of WG1, WG2 and WG3 and the conclusions and recommendations of all four WGs. The Forum’s main themes were:

- ➢ Physics school teachers’ education

- HOPE in perspective

The forum included a poster session of 28 poster presentations by participants from partners and associated partners and by students.

Again the invited speakers were selected to introduce the themes and compliment and stimulate the related presentations by other attendees.

- Hans Fischer, University of Duisberg/Essen, Germany: Professional knowledge of science teachers and consequences for teacher education.
- Laurence Viennot, University Denis Diderot, France: Critical reasoning as a component of teacher formation.
- Pratibha Jolly, University of Delhi, India: Global challenges in physics education.

The programme was again completed by two Round Table discussions - “Teacher needs in the different contexts” and an ambitious overview of HOPE entitled “A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of Higher Education in Physics within a European context in the light of the activities and results of HOPE”.

ACTIVITIES IN SUMMARY

The results and conclusions presented at the three Forums by the leaders and members of the four WGs were the outcomes of an extensive programme of activities arising from the discussions at the WG meetings and the decisions reached there. Together these formed an integrated examination of the life cycle of a physics student from the teaching of physics in schools to generic graduate skills via the influences on young people that inspired them to study physics and new approaches to teaching and issues affecting the mobility of students. In summary these were:

- A questionnaire based investigation of first year university physics students which asked students about the importance of their **internal** wishes/motivations (internal “drive”) for choosing to study physics at university and also asked questions about the importance of various **external** influences on them which led to these wishes/motivations.
- An interview based investigation of the views of first year university physics students. The views investigated were mainly on their reasons for choosing physics, on their background and also on whether they were happy with the course on which they were enrolled on. It “drilled down” into their responses to the above questionnaire as well as exploring background information.
- A questionnaire based investigation of factors affecting secondary school students’ attitudes to physics.
- A template based investigation into activities in which university physics departments cooperate with schools including Master-Classes, competitions and outreach.
- A questionnaire based investigation of physics graduates’ competences by comparing the experiences of graduates within the context of their current jobs with (i) how these skills were developed during their studies, and (ii).from the perspective of their employers along with their views on skills development within undergraduate physics degrees.
- Questionnaire based investigations of (i) the relevance of the generic competences identified by the Tuning Project for Physics Graduates to explore whether new competences are required in order to prepare physics graduates for the workplace outside of research, (ii) the extent to which physics departments (or universities as a

whole) have introduced these new competences and how they are assessed, and (iii) the views of physics academic staff on the relevance and importance and merits of these (new) competences to ensure physics graduates are properly prepared for employment.

- A questionnaire based investigation of current practice from physics departments on the specific innovation, entrepreneurship and enterprise competences that they include in the educational experiences and learning opportunities offered to their physics students including case studies of good and interesting practice.
- A questionnaire based investigation of the scale of mobility of physics students (Erasmus, bachelor-master mobility, non-EU etc) and possible factors affecting it (language, tuition fees etc).
- A template based investigation of the issues surrounding the adoption of innovative or alternative methods in physics teaching to identify reasons that can hinder the development of such methods of teaching.
- A questionnaire based investigation of (i) the shortage or otherwise of school physics teachers and related issues, (ii) the involvement of university physics departments in school physics teacher education, (iii) the routes to professional teacher status and physics requirements for secondary and primary schools, and (iv) continuing professional development of school physics teachers.

The data, results and detailed conclusions arising from these investigations are to be found in the reports generated by each of the four WGs. They have been disseminated, and will continue to be in the immediate future, as publications in peer reviewed journals and as invited and contributed papers at international (Europe and North and South America) and national conferences.

RESULTS AND RECOMMENDATIONS - AN OUTLINE

Inspiring the young: *First Year University Physics Students questionnaire*

The First Year University Physics Students Questionnaire garnered 2485 responses from 34 universities in 16 European countries making it one of the largest consultations of its kind ever attempted and ensuring confidence in subsequent interpretation and conclusions. It was designed to discover **successful factors** which influenced them since these students had already acted on their decision to study physics at university. There were 20 questions which asked students to rate the importance of various factors and external influences, along with 9 other questions on the age of first interest in physics, gender, school type, other university subjects considered and an open response question on other reasons for choosing physics.

The key outcomes were:

- “Internal” factors, particularly a wish to understand how physics explains things, are rated very highly as a reason for studying physics at university and dominate over a wish to enhance employment prospects, and external factors in general.
- The “External” influence with the highest mean score is the Internet.
- The “External” influence with the greatest number of highly rated responses is “Making or using a physics based device” implying that external influences that involve the active participation of students are the most effective.
- The percentage of female students of physics varies widely from country to country with the highest percentage being in Eastern Europe and the Balkans.

- Gender effects in responses to particular questions seem to be small, however, advice from the family is more influential for female students than for male students, the internet is more influential for male students than female students and female students become very interested in physics at an earlier age than male students.

***Inspiring the young**: First Year University Physics Students interviews*

The aims of this investigation were to “zoom-in” on responses to the above questionnaire in order to better understand the views of students, and to explore with students their level of satisfaction or dissatisfaction with their physics course and their reasons for possibly considering “dropping-out” - a significant issue for some partners. Interviews of 112 students (54% from Italy) from 16 universities who had responded to the First Year University Physics Students questionnaire were performed and analysed according to a shared template and coding scheme.

As well as confirming the main message coming from the questionnaire concerning the dominant importance of a wish to understand the world and universe, the interviews revealed that students were also attracted to physics because they saw it as a special way to investigate and to think about the world around them, particularly as a way of explaining things through basic principles and laws of nature. Some students were attracted by the mathematically based thinking involved in physics and others in the use of experiments as a way of achieving understanding. Although the questionnaire did not indicate a strong inspirational effect from a physics teacher, in the interviews the majority of students mentioned a teacher as being important.

***Inspiring the young**: Secondary School Physics Students questionnaire (SSQ)*

To complement the surveys of first year physics students, the school-university transition for secondary school students talented in physics was targeted; “talented” in this case meant students who were selected to participate in physics Olympiads, Masterclasses, summer schools and laboratories. As with the First Year University Physics Students Questionnaire, there was a large response in excess of 1500 replies from 13 countries, but again only a brief mention can be made of some of the general trends that emerged from different methods of analysis such as:

- The large majority (79%) of the students (95% male) demonstrated high interest in physics and a thirst for knowledge, but just a small percentage (23%) had decided to study for a physics degree.
- From SSQ data, some typical comments are the following: “physics is too difficult”; “I’m more interested in other science subjects, maths, engineering”; “recently my interest in physics unfortunately drastically declined”; “physics is too general and not applicable enough”; “I’m not sure of a future job”; “I think there are more job opportunities in engineering”; “I do not want to become a physics researcher or teacher”.

A detailed statistical analysis of the data gives the following priority objectives to increase the intention to study physics:

i. enhancing the professionalism of teachers by improving initial and in-service teacher preparation at all levels,

ii. promoting high-quality science teaching/learning starting from kindergarten or primary,

iii. providing students with active learning and engagement opportunities,

iv. establishing university-school joint initiatives for the dissemination of scientific culture inside and outside schools and working with schools in the dissemination of good practice, and information on research, modern physics and the career opportunities for physics graduates,

v. offering differentiated stimuli to gifted students, activating and sustaining their early interest for science, and promoting initiatives for excellence such as Olympiads and summer schools with direct involvement in highly demanding tasks.

vi. promoting joint research for the study of innovative proposals and the learning of students.

Physics graduates' competences

The views of partner physics departments' alumni working in sectors outside of academia and education were sought on physics graduates' competences, or "soft skills" as they are also known. They were asked to rate those competences that were very important for their job. Those most highly rated were:

- Problem solving and analytical thinking
- Searching for information
- Oral communication and presentation skills
- Teamwork
- English language
- Innovative thinking
- Autonomy
- Organization skills/project management
- Technological knowledge
- Interdisciplinary communication

While their employers came to similar conclusions when surveyed, as did the invited speakers from industry at WG 2 meetings, most physics alumni felt there was a discrepancy with respect to their own experience of the emphasis placed on these competences during their period of study at university.

A minority of the partner physics departments consider the development of entrepreneurial skills as (very) important for their physics curriculum. For the majority of departments which consider this development as (very) important, their strategy is linked to an institutional strategy. There are a number of interesting approaches by physics departments to deliver activities and/or courses to acquire entrepreneurial/enterprise skills offered by physics staff, staff from other departments or from outside university.

It is clear that among the competences needed for the work place outside academia and education, and certainly in an entrepreneurial environment, innovative and entrepreneurial competences have become more important over recent years and will be part of the "skills for the future". As a large percentage of physics graduates will look for a job outside academia/research and education, it is necessary that universities properly prepare them. In the opinion of employers, (physics) graduates are - in general - less well prepared for this job market than from the universities' perspective. However, there is a growing awareness in universities of this as shown by the many varied examples of good practice collected by HOPE from different countries involving innovative teaching and activities that promote the acquisition of these competences.

HOPE recommends that physics departments should formulate a vision as to how they would prepare their students better for the future job market with respect to the acquisition of such competences. Ideally this should be derived from a university level strategy, but they must first audit their courses to discover if and how competences are acquired inside the physics curriculum at this moment. Then if improvement is needed, use examples of good practice as inspiration, collaborate with other departments that might have the necessary expertise, attempt to integrate competences into appropriate coursework and not in isolation, and finally involve and seek the opinions of alumni working in sectors outside of academia and education and employers of such alumni.

Student mobility

Data was collected to gather the impact of transnational mobility in European physics degrees, both at the Bachelor and Master levels, as well as vertical mobility between Bachelor and Master programmes. The aim of the survey was not intended to provide a full map of mobility schemes across Europe but rather a snapshot of student mobility in physics. From the data collected among 21 partners in 15 countries the following conclusions can be deduced:

- The introduction of the Bologna system appears to have reduced mobility within the Bachelor degree, except where there are inter-university agreements.
- The Bologna system has the potential to make it much easier to attract students from outside Europe, but this does not seem to be true in practice.
- Outside factors such as student fees, different funding systems and language of tuition have a substantial effect on students by dissuading them from moving between universities and countries.

Innovative teaching methods in physics

Information on innovative or alternative methods in physics teaching was collected to investigate, not only the variety of teaching methods employed, but also their implementation and dissemination in order to identify what if any impediments discourage academic staff adopting them. Based on the practices collected, invited talks at Forums and WG meetings, and Round Tables, the following conclusions can be drawn regarding alternative teaching methods:

- The reasons for introducing innovative teaching methods are various - motivating students, improving learning outcomes, reducing drop-out after first year… but what they all have in common is to make students more active and develop self-learning skills.
- Generally, the implementation of innovative methods is based on personal initiatives, usually supported and encouraged by the department.
- Difficulties can arise when departments or institutions are willing to develop such initiatives at larger scales for different reasons such as (i) colleagues may be reluctant to introduce initiatives, (ii) financial considerations can hinder expansion as these methods are often more costly than traditional teaching, (iii) additional funding is usually necessary in the start-up phase since time is needed to produce new material and learn how to use it.
- Innovative methods help to improve student autonomy, self-learning skills, motivation and even learning outcomes and final performance.
- It is difficult to quantify the effect of such approaches to teaching and learning since in most cases small groups of students are involved.

- There needs to be wider dissemination of the results of Physics Education Research in this area.
- The profile of innovation in physics teaching needs to be raised in university physics departments, particularly in those countries with a periodic research assessment exercise where the focus is overwhelmingly on research as a way to achieve financial security. They need to devote financial and human resources to this area and recognise work done by academic staff as contributing to career development.

Improvement in the training of physics teachers: *teacher recruitment*

Many countries suffer from a shortage of physics teachers or foresee such a shortage due to a lack of physics teaching students and physics students in general and low attractiveness (finances, reputation) of the profession of a teacher. Only a few countries have established a successful programme to overcome this situation. There are problems associated with both the parallel and sequential routes to obtaining the physics content and didactical knowledge necessary for qualification as a physics teacher. An alternative is a semi-parallel route of a full Bachelor in physics and a Master in physics teaching. The results of WG1's questionnaire to first-year physics students confirm that the desire to become a physics teacher is low, and therefore an offer after a physics degree of an attractive and well-founded study program (with regard to content and time management) could recruit suitably qualified persons. Official programmes by governments and universities should be put in place to counteract the shortage of physics teachers. The more stakeholders on different levels (government, universities, unions,…) that cooperate, the more likely it is that such a programme will be successful.

Improvement in the training of physics teachers: *Involvement of physics departments and Physics Education Research*

Approximately 2/3 of HOPE's partner institutions contribute to the training of physics teachers for secondary schools, but rarely for primary schools. These institutions are not just those engaged in physics education research (PER) although departments involved in PER also take part in the design of materials for schools. Education at university level needs to be research based and research integrated and this principle should also apply to physics education. Hence, institutions offering training programmes for teacher education should provide facilities for PER as the design of material for schools is desirable in order to create a close link between PER and actual teaching. Unfortunately PER is considered less important for an academic career compared to mainstream physics research. Consequently, academic staff working in PER should attempt to increase the visibility of their research among their peers, PhDs on physics teaching should be promoted by physics departments with PER activities. This will facilitate a career in PER and in turn provide qualified researchers of PER who can contribute to a research-based education of future physics teachers.

Improvement in the training of physics teachers: *Continuing Professional Development*

The many partners are involved in some kind of Continuing Professional Development (CPD), mainly as initiatives arising at the university departments, but only a few take part in their evaluation. HOPE recommends that institutions which are not involved in in-service programmes should start such actions based on their expertise in PER and teacher training, and schools and teachers should be encouraged to express suggestions in which way physics departments can support science teaching at different levels and more institutions should take part in evaluation. Communities of educational research, with partners from university and schools, should be enhanced and governments should support and stimulate in-service teachers in their CPD, both financially and organizationally.

Improvement in the training of teachers: *lower secondary and primary schools*

Notwithstanding the difficulties in making such comparisons, the education of upper and lower secondary school teachers shows that, on the average, there is substantially less physics education and physics didactics for lower secondary school teachers, whereas there is slightly more education in pedagogy and in-school training. In many countries an education in science is a precursor to physics teaching but unfortunately, science teachers are very often not educated in physics.

Since physics education at the lower secondary school generates the basis for an understanding and interest in physics, more attention should be paid to the physics education of those teachers, and so not only teachers of upper secondary schools but also of lower secondary schools should have a university-education in physics; teachers in the latter case usually have a general education with little specialization in science and almost none in physics.

Science in schools is frequently dominated by biology, and this situation is more extreme at primary school level. The general education of a primary school teacher should include a fair balance between biology, chemistry and physics.

HOPE’S RECOMMENDATIONS FOR STAKEHOLDERS

The conclusions and outcomes outlined in the preceding sections may be summarised as recommendations for the important stakeholders involved in physics education at all levels.

Universities - physics departments

Inspiring the young

- Efforts to attract students to physics degree courses at university should emphasize its intrinsic interest as satisfying a basic urge to understand the world.
- The career flexibility of physics graduates as general problem solvers should be emphasised as well as the attractions of a career in research.
- Promotion of physics to young people via outreach should attempt to get them actively involved in practical activities involving physics rather than being passive receivers. It should also be noted that inviting school parties to visit universities is more effective than having staff visit schools.
- Establish university-school joint initiatives for the dissemination of scientific culture inside and outside schools and work with schools in the dissemination of good practice, and information on research, modern physics and the career opportunities for physics graduates,
- Offer differentiated stimuli to gifted students to activate and sustain their early interest for science, and promote initiatives for excellence such as Olympiads and summer schools with direct involvement in highly demanding tasks.

Physics graduates’ competences

- Formulate a vision as to how to prepare their students better for the future job market with respect to the acquisition of innovative competences, for example by first auditing their courses to discover if and how these are acquired inside the physics curriculum and attempt to integrate them into appropriate coursework, involving alumni and employers of alumni.

Innovative teaching

- Devote financial and human resources to the promotion and development of teaching, the training of academic staff, and recognise the associated innovation and research by academic staff as contributing to their career progression.

Student mobility

- Develop inter-university curricula to increase the opportunities for student mobility.
- Encourage short-term mobility at bachelor and master level, including research placements by such means as advertising on an international level such as via social media, physics student associations, Erasmus coordinators etc..
- Consider developing curricula in English (if not already the standard language of education in the institution) to enhance its attractiveness for international recruitment.

Teacher training

- Institutions offering training programmes for teacher education should be engaged in Physics Education Research in order to provide a research based education for future physics teachers.
- Institutions not already involved in in-service development programmes should start such actions based on their expertise in PER and teacher training to support science teaching at different levels.

Science education policy makers and ministries/departments of education

Inspiring the young

- Physics education in schools and university physics degrees should be supported because it responds to deep wishes of young people to understand the world around them and at the same time provides them with adaptable skills for problem solving and contributing to the advance of technology which in turn leads to economic growth.
- Physics education in schools should be a way of understanding the world based on careful observation, experiments and mathematically based models.
- Recognising that it is never too early to expose children to the physical world, include physics (although not necessarily termed as "physics") in the school curriculum from primary or even pre-primary, along with appropriate practical activities.
- Develop resources for pre-secondary onwards which highlight the role of physics in the creation of the modern world and the career opportunities for physics graduates.

Teacher training

- Establish initiatives to counteract the shortage of physics teachers; the more stakeholders on different levels (government, universities, unions,…) that cooperate, the more likely such a programme will be successful.
- Recognise that physics teachers are physicists and hence only physics graduates should be qualified to teach physics.
- Enhance the professionalism of teachers by improving initial and in-service teacher preparation at all levels.

Physical societies and the physics community

Innovative teaching

- Disseminate the results of Physics Education Research on innovative teaching among the academic physics community by, for example, creating a national programme of pedagogical meetings for sharing new approaches to teaching.

Physics students

Student mobility

- Consider having at least one mobility period of minimum 3 months abroad during the first or second cycle in higher education.

Competences and innovative teaching

- If available, choose non-traditional or innovative teaching methods to enhance the learning experience and to improve the acquisition of those entrepreneurial competences that are highly valued by employers outside of academia or education.

Physics teachers

Inspiring the young

- Develop and exploit the various collaborations possible between school and university physics departments - visits, master classes, etc..
- From pre-secondary onwards, promote physics as a science and its contribution to technology, the concept of a “physicist” and related employment.

4. Partnerships

The composition of the HOPE consortium evolved from the combined and common memberships of EUPEN (European Physics Education Network, established 1995) and the subsequent STEPS (Stakeholders Tune European Physics Studies) (2005-08) and STEPS TWO (2008-11) projects. It comprised **71 full partners**, including 65 university physics departments, from **31 Lifelong Learning Programme (LLP)-eligible countries**, i.e. all of the European Union except Luxembourg which does not offer higher education in physics, along with Norway, Republic of Serbia, Switzerland and Turkey.

These **65 academic partners** award degrees in physics, physics-related subjects or physics education and their representatives have extensive experience of teaching and administration as well as European and international cooperation and are thus aware of national and international academic issues and policies. The **6 non-academic partners** completing the full partner pool include (i) **CERN** (European Organisation for Nuclear Research) with its track record of inspiring young people and teachers, providing summer internships for students, and of knowledge transfer and innovation of great value to Europe's economy, (ii) the **International Association of Physics Students** - an umbrella association of physics students from 18 European LLP countries, and (iii) a number of European based associations representing important stakeholders crucial for an optimized dissemination of the results such as the **European Physical Society** (EPS), with national branches in 41 countries representing more than 120,000 members and a strong physics education division, and the Italian Physical Society. The consortium is further enriched by **21 associated partners** from Europe (CH, CY, EL, ES, FR, IT, PL, RO, RU, SI, UK), North America (US) and South America (AG and BR) and India, (IN) again representing universities, learned societies, associations, industry and scientific centres.

The distribution of tasks was done on a fair basis, according to the expertise, interest and willingness of each partner. All persons, institutions and organisations directly involved and responsible for running the project activities have long standing experience in physics higher education. Many have well established links with secondary education. Most of the partners have played leading roles in either European Thematic Networks projects, Tuning Projects or other, proving excellence in networking activities and European cooperation. Many act as advisers for their sector, higher education institutions and national and European authorities.

As with most networks, a distinction can be made between (i) management and advisory duties as represented by the **Management Committee** (MC) and the **Advisory Board** (AB) and (ii) membership of the 4 **Work Groups** (WGs) although of course all members of the MC and AB were members of one or more WG. Each group had its own tasks and responsibilities, as proved by skills, expertise and previous experience. All activities were networking activities, involving always more than 5 partners. The MC comprised the coordinator from France together were two other partners (IT and UK) who were keen and willing to share and shoulder this administrative burden. The membership of the AB was drawn from senior partners in previous EUPEN and STEPS projects, whereas the leaders and deputy leaders of the four WGs involved partners from as many countries as possible.

The network partners have wide experience in enquiring, analysing, mapping and disseminating the results and most or their colleagues were experienced in "network work", having benefited from long term and fruitful cooperation in previous academic networks. The project was in the hands of a very experienced team, with proven daring, perseverance and authority with up to twenty years experience of the EUPEN and STEPS projects, in SOCRATES and Erasmus programmes. The five members of the Advisory Board, having a recognized experience in European physics educational projects, have been not only advisers, but they were actively involved in project activities and internal evaluation. New and younger staff persons from partners and associated partners were encouraged to actively participate.

The face-to-face meetings of working groups, with participation of almost all members of the respective working group, contributed to a solid partnership based on common interests, goals and friendship. The HOPE web-site was used as a tool for networking and easy access to all documents issued in the project framework, ensuring the flexibility and transparency of project activities. A highlight of the annual Forums and some of the WG meetings was the presence and involvement of students from all levels (bachelor, master, doctoral) who demonstrated maturity in the approach of their tasks and awareness concerning their role in every university. The sense of strong collegiality among partners was further maintained by the publication of a regular newsletter.

The HOPE project enhanced cooperation with scientific and professional organisations at national and European level via their full or associated status. They contributed to its work by providing speakers at Forums, supplying data for its investigations and assisting with publicity and dissemination. The following is a list of the non-university full and associated partners and other bodies with which HOPE has been involved; other than the first, they were all identified in the original submission in January 2013.

1. American Association of Physics Teachers (http://www.aapt.org/), associated partner
2. American Physical Society, Maryland, USA (http://www.aps.org/), associated partner
3. Argentine Physics Teacher Association (http://www.apfa.org.ar/pgm/d/), associated partner
4. Associazione per l'insegnamento della Fisica (Association for Physics Teaching), Parma, Italy (http://www.aif.it/), full partner
5. B M Birla Science Centre, Hyderabad, India (http://www.birlasciencecentre.org/), associated partner
6. CERN, European Organisation for Nuclear Research, Geneva, Switzerland (http://home.web.cern.ch/), full partner
7. European Physical Society, Mulhouse, France (http://www.eps.org/), full partner
8. GIREP, Groupe International de Recherche sur l'Enseignement de la Physique, (International Research Group on Physics Teaching) (https://girep.org/), associated partner
9. IBM, Zurich, associated partner
10. International Association of Physics Students, Mulhouse, France (http://www.iaps.info/), full partner
11. Institute of Physics, London, UK (http://www.iop.org/), associated partner
12. Musée Palais de la Découverte, Paris,

    (http://www.palais-decouverte.fr/fr/accueil/)
13. SECURE, Science Education Curriculum Research (http://www.secure-project.eu/),
14. Società Italiana di Fisica (Italian Physical Society), Bologna, Italy (http://www.sif.it/), full partner

5. Plans for the Future

With the cessation of funding for large academic networks under the Erasmus + programme, the HOPE community is unable to continue its investigations in a similar way and is thus formally disbanded. However, the bonds established during the three years of the project and indeed those established among various partners since the foundation of EUPEN (European Physics Education Network) in the mid-1990s will ensure that collaboration in some form will continue since many of HOPE's results require further study and have also prompted many new lines of research.

With the new Erasmus+ Strategic Partnerships funding opportunity for collaborative projects limiting the maximum size of consortia to about ten partners, HOPE facilitated the creation of new projects by hosting a brainstorming and "speed dating" session at its last Annual Forum in September 2016 in which partners interested in such activities had the opportunity to outline and debate their ideas.

As stressed throughout this report and indeed in the original submission to the European Commission, physics plays an essential and leading role in developing the economy of Europe and it can only do that by producing appropriately skilled physics graduates; this in turn depends on Europe's universities offering modern degree courses based on best practices but that can only be identified during joint activities. It is hoped that the change in funding policy will not bring to an end twenty years of fruitful international collaboration stretching from EUPEN to HOPE via STEPS and STEPS TWO..

6. Contribution to EU Policies

GENERAL COMMENTS

HOPE is a European project with partners from 31 European countries eligible for LLP and 5 other countries represented by associated partners. The outcomes of the project are meant for all higher education institutions providing physics and physics related degree courses, academics and students in Europe, as well as organisations which have a role in pre-university physics learning, or in quality assurance of education in physics. Each of the four themes of HOPE has significant relevance to European development. Positive developments in these areas and the project outcomes will not only help progress the Bologna Process in partner institutions, but will also help universities to move towards further improvement in the education of future scientists and physics teachers, and in the strength of the European workforce.

The principal aim of HOPE was to provide Europe with an increasing number of well-trained physics graduates by examining the full cycle, i.e. the teaching of physics in schools, the inspiring of school children to decide to study physics in university, and the skills with which they will leave university. From the perspective of European wide education and employability it is no longer useful to limit frameworks at subject area and sectoral level to regions and nations. Examples of good and best practice can serve as examples for other countries, institutions and organizations.

HOPE dissemination tools (the Forums, web-site, booklet, papers in peer reviewed journals and presentations at national and international conferences, with results and outcomes of the project) are supporting (i) the search for tactics to recruit the best school leavers to physics, (ii) the identification of graduate skills and the comparison between their provision by partner universities and the needs of a range of employers, (iii) the barriers or otherwise to international recruitment and mobility between the bachelor and master phases, and (iv) the recruitment and career options for physics teachers. All partners have been encouraged to use public HOPE materials in all kinds of events important for academics and students, governmental bodies, EPS journals and other European periodicals.

SPECIFIC COMMENTS

HOPE supports a range of specific EU policies - those of the Education and Training 2020 Work Programme and the Lifelong Learning Programme under which the academic network was funded, as outlined here.

Education and Training 2020 Work Programme (ET2020)

HOPE's four themes and their associated aims directly address education and training and support specific objectives and aims of ET2020 as follows:

- Among the four common objectives identified by EU countries within ET2020 are (i) improving the quality and efficiency of education and training **[HOPE WG2, WG3, WG4]**, and (ii) enhancing creativity and innovation, including entrepreneurship, at all levels of education and training **[HOPE WG2]**.
- Among the five aims of the EU's modernisation agenda are (i) increasing the number of higher education graduates **[HOPE WG1, WG4],** (ii) improving the quality and relevance of teaching and learning **[HOPE WG2, WG3]**, and (iii) strengthening the "knowledge triangle", linking education, research, and innovation **[HOPE WG2].** One of the common challenges of the EU's role in education and training is the skills deficit in

the workforce (including transversal skills such as the ability to learn and initiative training) **[HOPE WG2]**.

Lifelong Learning Programme (LLP)

Similarly, HOPE is also working to achieve or contribute to the following specific objectives of LLP::

- LLP-Objective-k: To encourage the best use of results, innovative products and processes and to exchange good practice in the fields covered by the Lifelong Learning Programme, in order to improve the quality of education and training. **[HOPE WG1, WG2, WG3, WG4]**
- LLP-Objective-e: To help promote creativity, competitiveness, employability and the growth of an entrepreneurial spirit. **[HOPE WG2]**
- ERA-SpObj-b: To reinforce the contribution of higher education and advanced vocational education to the process of innovation. **[HOPE WG2]**
- ERA-SpObj-a: To support the achievement of a European Area of Higher Education. **[HOPE WG1, WG2, WG3]**
- ERA-OpObj-5: To facilitate the development of innovative practices in education and training at tertiary level, and their transfer, including from one participating country to others. **[HOPE WG3]**
- ERA-OpObj-4: To improve the quality and to increase the volume of co-operation between higher education institutions and enterprises. **[HOPE WG2]**