Crossing the Borders and the Cultural Gaps for Educating PhDs in Software Engineering

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***Abstract*—Software systems have established themselves as the heart of business and everyday living, and as the pillar of the emerging global digital economy. This puts pressure on educational institutions to train people for the continuously evolving software industry, which puts additional demand for new PhDs and educators. While large universities and research centres have the required expertise and infrastructure to providing a cost-effective training by research as well as covering wide spectrum of software engineering topics, the situation in small universities with limited resources is challenging. This is even more difficult for some countries where the discipline of software engineering is totally new, which is the case of emerging countries. This paper describes the Pathways to PhDs project funded by the European Commission. The long-term aim is to support the development, modernization and international visibility and excellence of higher education, namely education by research at the PhD level in Europe, while helping partner countries to develop new PhD programs and consolidate existing ones in the field of computing in the area of software engineering. This paper presents the creation of a common educational framework that consist of seven specialized short-intensive schools, each of them feature the expertise and "savoir-faire" of participating universities. The collaboration and communication among partners and the schools is supported by an innovative communication platform, which is also presented in the paper.**

Keywords—PhD education; cross-culture and multi-institution education; problem-based learning; soft skills; training by research

I. INTRODUCTION

Software engineering (SE) education at the PhD level differs in content and structure from the master and bachelor ones. For example, some masters-level programs may be principally concerned with management of software activities, whereas PhDs should be focused on methods and tools for software development. For example, the PhD program at the Lappeenranta University of Technology (LUT) is focused on empirical, human and sustainability aspects in software systems. The master's program is a more general program that also includes courses from open innovation and business. PhD studies differ in career emphasis. PhD programs, by their nature, prepare graduates for research and academic teaching positions – though many PhD graduates choose to work in industrial development instead. Some of the master's programs are designed specifically to support PhD programs. Still, most master's programs are designed to prepare their graduates for professional practice at a high level of technical or management responsibility (and not for entry to a PhD program).

PhD studies are most often an individualized track, meaning that if two PhDs are in the same program, they may have a different profile in content and structure. Indeed, while focusing on a specific research topic (generally the supervisor's interest), students are also required to develop a deep understanding of a wider range of topics such as software architecture and design, software assurance and program analysis, measurement and tools, teams and organizations, and end-user programming in the field of software engineering. They are required to master and develop their skills in conducting and communicating research results, managing research activities as well applying for funds.

We argue that PhDs in software engineering, like any professional engineers, should be prepared to work in multidisciplinary teams, multi-cultural contexts that cross many borders and organizations. They should have exposure to other related concerns such as business, management, engineering profession and ethics. While some PhDs continue in the academia, a majority of PhDs will work in industry and will require a wide range of skills. For industry, PhDs should be able to work on problems on the cutting edge, similar to what they do for academic research - except that their ideas should get implemented.

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The number of universities offering software engineering as a separate doctoral program is very limited. Most often, software engineering is offered in universities as a concentrated area of study for computer science (CS), computer engineering or even management of information systems majors. Yet universities should be able to train students in very specialized niches of research. Therefore, it is almost difficult, especially for small universities with limited resources, to provide such training opportunities.

Even though various software engineering programs have been running since late 80s, many universities around the globe are facing difficulties in addressing the current software engineering challenges and needs. The contents of programs are still the same although the context has drastically changed [1]. Although the world has changed and education has been "standardized" by initiative such Bologna process [2], differences still exist because of different cultures. Additionally, Bologna did not address the PhDs level education except at a very general level [3]. ACM/IEEE Software Engineering Curricula [4] defines the content guidelines for the undergrad and graduates programs in software engineering but does not define the contents for PhDs. The Software Engineering Body of Knowledge (SWEBOK, [5]) can be used as a guide for building bachelor's and master's degrees, but have not been used for PhDs.

This paper details the Pathways to PhDs (PWs@PhD) project. It reports, describes, and reflects on the initial impact the project has on the target countries, Jordan and Russia. How a small university can offer a PhD education in software engineering? How various universities can put in common their "savoir faire" in software engineering? How to manage a cross-country and a multi-cultural program that puts together universities from different regions of the world? The PWs@PhD program offers a path to address such challenges.

The European Erasmus plus project connects four countries from the European Union with two target countries, Russia and Jordan. Both have very limited resources in software engineering and there is a huge demand for advanced professionals in the industry.

Taran and Rosso-Llopart [6] stated that Russians tend to add value in the area of very complex software engineering problems domain in which they may use their strengths in technical field involving complex mathematical problems. However, there is no evidence how the wider software engineering body of knowledge has been integrated into Russian software engineering education. Al-Zaghoul et al. [7] analyzed software engineering education in Jordan. They state that software engineering education at least in their case university, ISRA University, complies rather well with SWEBOK. However, Hanna et al. [8] highlighted that "software engineering graduates in Jordan lack the required knowledge and skills to join the software industry".

As such, there seems to be a need for further actions in both of the target countries. Both countries are considering launching software engineering and management specific PhD programs in the near future. The project presented here is created to help these countries, among others.

II. BACKGROUND AND OVERVIEW

Each country and university has its own PhD educational system. Although there is often less difference between two national systems in Europe than between a European system and the US system, national and regional systems have created barriers to professional mobility. Increased awareness of the difficulty posed by these barriers in a mobile world gave rise to a decades-long effort to harmonize and integrate higher educational systems. The most known harmonization initiative is the Bologna process, which created a framework for higher education throughout Europe. Bologna is also being used by European states that are not members of the EU [9]. The Bologna process recognizes three distinct levels of academic qualification called first-, second-, and third-cycle degrees, corresponding roughly to the bachelor's, master's and doctoral degrees used in the United States and other Anglo-Saxon countries such as Canada and Australia [10]. There is no concrete credits range in Bologna process at the PhD level, which leaves the door open for universities to define their own requirements for the PhD degree [3]. These vary, for each discipline differs in length and comprehensiveness.

In Europe, PhDs usually require 2-5 years of specialization, primarily individualized training by research under a supervisor. In order to complete the PhD degree, for example some universities with a separate software engineering program like the Lappeenranta University of Technology, each student is required to:

- Contribute to scientific knowledge in software engineering by engaging in directed research. This is the central element of the PhD program, and students should spend at least half their time on research from the first semester onward.
- Develop a broad foundation in software engineering and specific intellectual skills by passing 40 university units worth of graduate courses, with certain distribution requirements
- Acquire and demonstrate teaching skills by serving as a teaching assistant
- Acquire and demonstrate oral and written communication skills by writing about research and participating in a software research seminar.
- Demonstrate, through an issue-focused oral presentation and written practicum report, an understanding of software engineering that is grounded in practice.

III. AN OVERVIEW OF THE PWS@PHD PROGRAM

PWs@PhD is a 3-year EU funded Erasmus+ project. The educational contents of the program are based on the Software Engineering Body of Knowledge (SWEBOK), and is implemented as a set of schools arranged by the project partners.

The SWEBOK Guide represents a broad consensus regarding what a software engineering professional should know and competent software engineers should be equipped with this knowledge for its application. Very early on, SWEBOK has influenced both academia and industry from various perspectives [11]: maturation of software engineering as a recognized profession, development and evaluation of

software engineering undergraduate and graduate programs and their accreditation, certification or licensing of software engineers, professional development and professional societies (over 100 citations of such evidences in [11]). For example, the SWEBOK provides a foundation for curriculum development at the bachelor and master levels with referencing to *generally accepted* knowledge with widespread consensus validating its value and effectiveness" [12], and it distinguishes from advanced and research knowledge (on the grounds of maturity) and from specialized knowledge (on the grounds of generality of application). The SWEBOK structure of Knowledge Areas (KA) can be used as a high-level competency model for both individuals and organizational capabilities considered relative to each KA and their subdivisions, to identify coverage and depth of knowledge required in various contexts and educational programs.

A doctoral education curriculum can also refer to the SWEBOK Guide for identifying not only the topics within the knowledge areas but as well the pedagogical categories commonly attributed to Benjamin Bloom ([13], [14]), with educational objectives across all of the six categories representing increasing depth: knowledge, comprehension, application, analysis, synthesis, and evaluation. At the doctoral level, the development of software engineering curriculum must be forward-looking to prepare the doctoral students to explore, through their selected topics of research, the development and validation through a scientific approach of new knowledge to improve both specialization and generality of software engineering knowledge.

Each school in the PWs@PhD project has a special theme covering the core of software engineering education. Teachers from partner universities arrange the course modules in different schools. PhD students from different locations participate in the schools supporting their individual research paths. Fig. 1 presents one possible flow of a student through the PWs@PhD program. It shows how pooling of resources, guided by the software engineering core knowledge, allows increased opportunities and an individualized path of a student through a PhD program.

The core of the project are seven schools with different educational focuses and an innovative integrative framework, FASE for educating PhD software engineering students. Each of the schools includes several training activities, mostly short courses or discussion of a case study (3-4h). Each of these seven schools take place once in one of the seven locations of the project (two in Russia, one each in Finland, Germany, Denmark, UK and Jordan). The different pedagogical activities are designed to help the students to acquire the different area of knowledge via case studies and practical problem solving. A full list of partners and locations is presented at the FASE website (http://fase.it.lut.fi/).

The schools cover technical aspects of software engineering, as well as business and human aspects, which is not possible in traditional programs, as it requires involvement of business schools. We have also adopted the problem-based learning (PBL) approach. Aalborg University is a leading institution in using this approach, its centre for PBL is recognized by UNESCO for its expertise (see Alborg University UNESCO site http://www.ucpbl.net). A specific training will be provided to all teachers and professors involved in the different teaching activities. Beside the training activities (courses focused on specific software engineering topics), we also plan for other activities, such as research lab visits, and demonstrations of tools to help students to gain practical expertise in research methods and approaches in the software engineering domain.

Fig. 2 summarizes the key elements of the PWs@PhD project. In addition to the SWEBOK basis for the seven schools, the PWs@PhD project uses international advisory board to reflect the national priorities and needs in the software engineering field. The FASE forum acts a common platform for discussions between students and teachers, internal and external stakeholders.

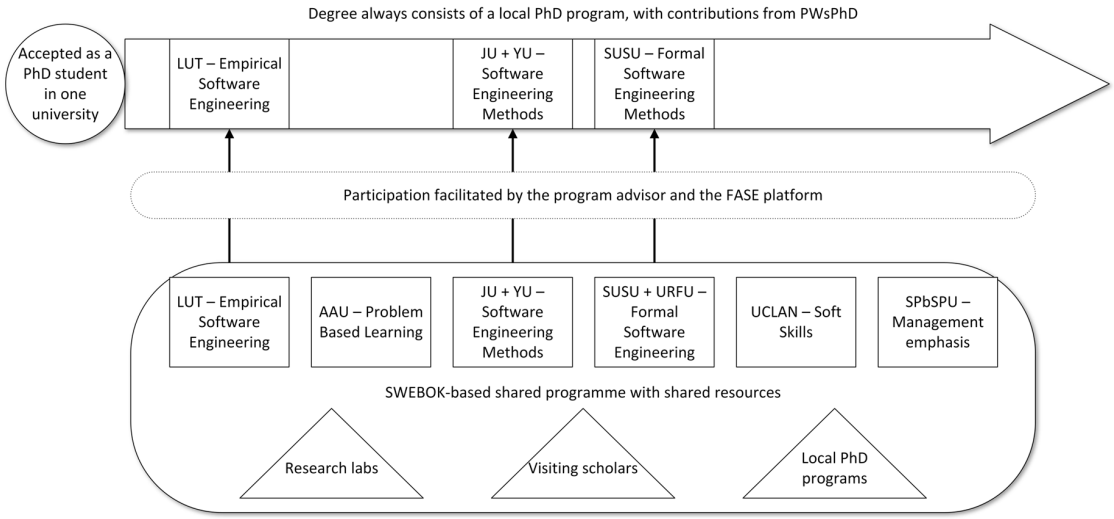

Fig. 1. The program's overall concept for individualized paths

The PWs@PhD project objectives and innovative aspects are:

PhD programs and profiles: Help the partner countries to develop and improve their PhD education and research while establishing PhD program profiles in the software engineering knowledge areas (SWEBOK). This project is built to support partners in sharing their own expertise, courses and labs, while helping each other to improve.

PhD student training: Train the next generation of highly qualified academic researchers and educators in different research areas of software engineering. The wide range of PhD students that will be involved in the project will acquire deep understanding of research methods in addition to a wide range of related skills. They will be skilled in writing, presenting and interacting with the international research community via projects and conferences. By visiting labs and taking courses at different locations, PhD students will have a unique opportunity to discover a wider range of research niches in software engineering than they see in their own university. The students will have an opportunity to network themselves and to participate in different ongoing research projects at the different partners' locations.

Academic research and professors: Give the opportunity to all participating professors and their research groups and centers to know each other and to collaborate on joint research projects, courses, and strategic partnerships including joint research infrastructure, publication and PhD supervisions. Professors accompanying or providing teaching in the different locations will be able to be in touch with potential PhD candidate and contribute to develop co-supervision with local colleagues.

Target countries and institutions: Support target countries in developing their capacity in software engineering education at the PhD level as well as fundamental research. Both for Russia and Jordan, this project will help these countries to build their own PhD programs in software engineering while discussing with EU partners for possibilities to establish joint doctoral programs.

European universities and countries: Help European partner universities to develop their capacity to build a sustainable collaboration with partners with different research traditions and cultural backgrounds in international and multi-disciplinary environment. The project is a way for delivering education that can supplement the European educational system. Beyond dual PhD programs, the project opens the door for the development of joint research ventures, common campuses and distributed research centres.

As already highlighted, the PWs@PhD project focuses on software engineering discipline that has the same core as computer science – algorithms and mathematical foundations – but as an applied technology-oriented discipline software engineering has also strong connections with various other disciplines such as engineering, management, and psychology as highlighted by the SWEBOK. The SWEBOK defines 15 key knowledge areas and seven closely related disciplines. Therefore, providing a high-level education in all these key knowledge areas at a PhD level is a challenging task, especially for newly established programs.

An informal survey shows us that most often the universities do not have expertise in all these areas, since typically software engineering education is a part of a computer science program. Thus, the overall aim of the project is to support the development, modernization and internalization of higher education in the target countries while helping also EU countries in strengthening their PhD programs and them making more

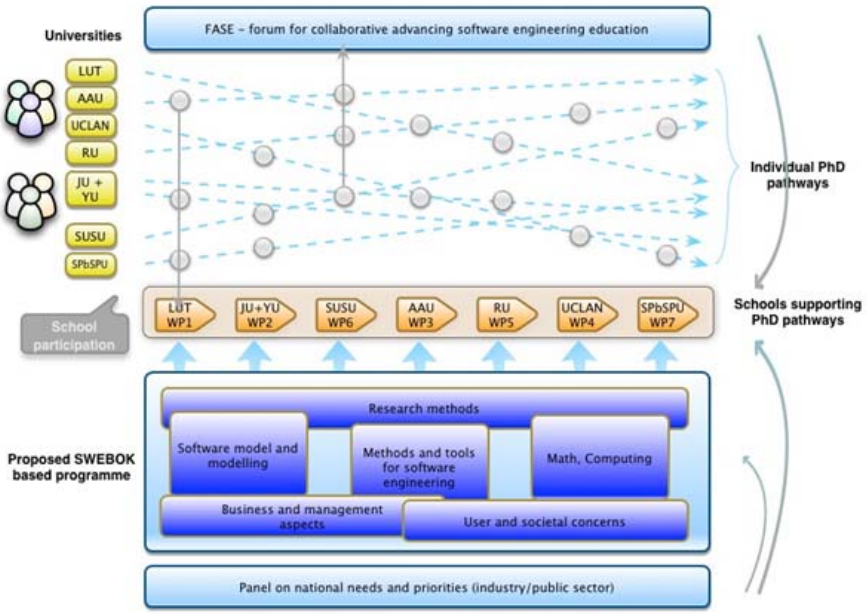

Fig. 2. Structure and key components of the program

attractive for international students. The project will create an opportunity to build and offer a sustainable multi-disciplinary, multi-cultural and multi-region, multi-institution, and multi-perspectives program for educating the next generation of software engineering professors.

IV. MANAGING A MULTI-CULTURAL AND CROSS-BORDER EDUCATIONAL PROGRAM

There are technical, business and academic reasons for selecting the participants and building the consortium of the project. The technical rationale is based on the statement of Carnegie Mellon University and its Software Engineering Institute[1]. SE education at graduate level requires a combination of three key competencies. Our consortium is built to cover the **technology competence** which is about the core computing concepts relating to data structures, algorithms, programming languages and their semantics, analysis, computability, computational models, etc.; this is the core content of the discipline. This technical knowledge is applied through a **body of engineering knowledge** related to architecture, the process of engineering, tradeoffs and costs, conventionalization and standards, quality and assurance, etc.; this provides the approach to design and problem solving that respects the pragmatic issues of the applications. These are complemented by the **human, social and economic context of the engineering** effort, which includes the process of creating and evolving artifacts, and issues related to policy, markets, usability, and socio-economic impacts; this provides a basis for shaping the engineered artifacts to be fit for their intended use.

From the academic perspective, the members have been selected based on their expertise to **address the core areas of knowledge** defined in the SWEBOK, and the soft skills detailed in planned schools and modules. Built on the top of the existing programs at the partners, the program benefits from the acknowledged Russian school of mathematics and fundamental computing, and the long tradition of computer science education in the four EU partners. It benefits from the Jordan education system, which is based on the North American model of higher education. Universities in Jordan adhere to the ABET requirements for accreditation (Accreditation Board of Engineering and Education). The Jordan universities are the top three in the country and are all looking for partners with whom to develop graduate level software engineering programs.

The PWs@PhD project develops a strategic network, a program, and a framework for education in software engineering. All the partner universities have specific expertise in different areas that the program will make available for all the other partners in the project. In practice, the proposed program is structured in seven development work packages[2] (WPs). Each WP details a two-week intense school organized at different universities roughly every six months. Each university can nominate at least two PhD students to attend the different schools. Students are not required to attend all the seven schools. Target countries can also send their professors to the schools for training and research purposes. The intensive training schools in different knowledge areas and disciplines provide varying training and knowledge more than typical PhD student would encounter in one specific university. Individual students can select with their supervisor the best schools for the PhD student's research profile. Together they create the student's personal path in the proposed program which then is seen as a horizontal bridge on top of the existing programs in the different participating institutions.

PWs@PhD project follows the normal EU project management activities. These activities include the kickoff meeting in which roles and responsibilities will be reviewed and assigned. The kickoff meeting will be followed by the first meetings of the DPB (Doctoral Program Board) and the Quality Assurance Management (QAM) Committee in which the quality plan will be refined and approved.

Different channels to collect feedback from outside the project will be set up:

1. FASE (Forum for Advancing Software Engineering Education)
2. The Panels for National Priorities and Needs
3. The International Scientific Advisory Board.

In the project, different tools for communication such a web site with a private section for the participants and presence or groups in various social media are used. The project team also monitors and controls the quality attributes via the continuous collection of data, analysis and recommendations for changes. To ensure the quality of the project, it was started with a proposal and adoption of quality plan during the kick-off meeting. A committee for quality assurance has been created to assess and supervise the work of the committees, WPs and participants of the project. This instance of the project works independently from the project. The chair of the quality committee is in charge of setting up a committee from the participants, associate partners, from university partners or elsewhere. The quality committee will include representatives from the different partners as well as external individuals from industry.

To increase the impact of the project and the long-term sustainability of the project, a dissemination and exploitation plan has been planned. It consists of building a framework, called "Put it all together", for training PhD students. A specific committee, the Doctoral Program Board (DPB), has been proposed to share individual expertise in PhD program design and exploitation and to build together the framework during the project. The DPB will be meeting periodically to discuss the framework. Members of this committee will be organizing workshops at different international conferences to promote the framework and its applications.

At the end of the project, the website of the project, the Moodle platform that includes all materials and resources related to the training activities, and the FASE (forum for advancing software engineering) platform will be maintained online by the partners at their locations. All the publications and final report will also be made available via the website. We also consider publishing a book that will include chapters from partners including contributions to the project. The book will

[1] http://www.sei.cmu.edu/

[2] http://fase.it.lut.fi/

detail also the put it all together framework as well as the recommendations for the different panels on national priorities and needs. FASE mailing list can be used to disseminate information to the whole consortium including associate members.

Several other actions will be taken to maintain the consortium in life such as proposing other projects between European countries, developing strategic partnership between countries for example Jordan/EU or EU/Russia. The project has been designed to providing partners with a unique platform for developing joint research projects and a fruitful collaboration. As part of the project, we will be organizing more than 20 visits to labs, research teams and centres, open not just for students but also for professors and representative from the different participating universities. This multi-level interaction is expected to result in joint research initiatives.

V. Presenting the concept of PhD school networks, cases of LUT (Finland) and Aalborg University (Denmark)

The program includes seven schools that are planned to occur every four months; each one provides an opportunity for all PhDs, researchers and professors from the eleven participating universities to meet, learn and share their expertise in one of the following areas:

- Model and modeling in software engineering
- Research methods and empirical software engineering
- HCI and human aspects in software engineering
- Software engineering models and modeling
- Formal methods in software and systems
- Management and business concerns
- Advanced software engineering

Any of participating universities have resources and infrastructure to cover all these areas. For all partners, this project offers an opportunity to offering their PhDs a deep exposure in these areas and at the same the project creates a platform for collaboration between staffs and professors. Each school includes a large set of training activities including:

- Short intensive research-oriented courses (one to two days)
- Lab visits
- Tools, demos and code camps (hackathons)
- Invited talks and seminars by leading researchers and practitioners
- Panels of national needs and priorities in Russia and Jordan
- Poster sessions by PhDs
- Keynote talk
- Brainstorming sessions
- Research papers workshop

To cite an inspiration for the project, in an article entitled "Twenty-First Century Leadership Challenges," published in May 2005 in Engineering Times [15], the magazine of the National Society of Professional Engineers, Ralph R. Peterson, the chairman and chief executive officer of ch2m hill, a global engineering firm, wrote:

"It's not enough to simply design and build projects. We must 1) grasp the totality of our client's mission, 2) develop solutions that add value to the client's mission, and 3) link our compensation to the value-added outcomes as defined by our clients. . . . No single firm can move the industry, but if our profession takes on the challenge . . . together we can make a difference. . . . As the developing and developed worlds strive to improve their economic prospects and quality of life, we will come to grips with the fact that we live in a finite world. Our profession's leadership challenge is to reposition itself as an effective steward of natural resources and the environment".

A. LUT School

Empirical investigations either for validation or for proof of concepts are important activities in software engineering research today. Doctoral students need to acquire knowledge and competencies in selecting and knowing how to apply correctly diverse research methods and tools. This is not an easy task for PhD students in computer science and software engineering because the benefits and challenges in using each method are not yet well catalogued. Another reason is that most often master programs in CS and SE do not cover such topics, even though in human sciences and business management school students have a deep exposure to research methods.

The LUT school aims at training students in a number of empirical software engineering methods and how they have been applied successfully to solve problems.

During the two weeks of the school (18.4.-1.5.2016), the 24 PhDs and 23 members of staff explored how to plan, administrate and analyse the results of a study using diverse methods (see Table 1 for the detailed program). Theoretical stances behind the methods, practical considerations in the application of the methods, and data collection were also briefly reviewed. Taken together, this information provides a suitable basis for both understanding and selecting from the variety of methods applicable to empirical software and information systems engineering.

Compared to existing programs in each of the eleven participating universities, students usually at best have one course on research methods or various seminars. LUT school provides a broader coverage of the research methods and how they have been applied in the field of software engineering research. Additionally, research methods were also presented by professors from the diverse participating universities and also invited guests.

B. Aalborg University School

In the project, it has been decided that the Problem Based Learning (PBL) approach is central for understanding and collaborating in software engineering. Problem Based Learning is an internationally recognized approach in which project work, work on authentic and realistic problems and collaboration is essential [16]. At Aalborg University, this means that all students do independent work, learn how to apply theory and research based knowledge, and develop communication and cooperation skills at the same time.

TABLE 1. LUT SCHOOL PROGRAM

Day	Key training activity	
1	Introduction to research methods inn software engineering	
2-3	Technical communication and writing	LUT Green Campus Tour
4	Use and abuse of statistical methods in research	
5	Software engineering experimental methods involving participants	
6	Conducting user and design science research in a living lab	Tour and overview of the CODER (Co-Design, Experimentation and Research with User Experiences) living lab
7	Grounded theory in software testing research	
8	Game research and usability studies	
9	Interactive Posters of LUT research (presented by Ph.D.'s in Software Engineering	
10	Research posters by students	

The skills the students gain are skills that the industry in Denmark (and other countries) require and seek when employing new persons.

The Aalborg University School aimed at providing the PhD students with insights into the Problem Based Learning principles by theoretically learning about these and then applying practical skills in exercises throughout the school. The school links the PBL learnings to software engineering by having representatives from the software engineering industry to present viewpoints on software engineering skills and to discuss with the PhD students. Other activities involved student presentations in plenum for staff, group work around software engineering topics, plenum discussions about what software engineering is, presentations to improve communication skills of PhD students, and doing reviews and constructive feedback to other students as part of abstract writing.

The Aalborg University School was held in August 14-28, 2016 with 26 students and 19 staff members from all partner institutions and countries. The students learned about team working, collaboration, communication skills, what it takes to be part of an international software engineering interest group where participants are different in their interests, experienced working across disciplinary boundaries, and communication in general.

The PhD students participating in this school represented well the broadness of the SWEBOK with respect to their PhD studies. The school benefitted of this, since one of the outcomes of the school should be to be able to communicate and collaborate across disciplines since this is an important skill for working in industry and also for academic positions in software engineering.

VI. HOW THE PROGRAM IS DEVELOPING THE DISCIPLINE OF SOFTWARE ENGINEERING IN EMERGING COUNTRIES

A. The Case of Russia

Recent reform of the Russian education system led to transformation of the post-graduate school, which is called “aspirantura”, to the third-cycle university education in accordance with the Bologna process. During the limited amount of time since the beginning of the reform in 2013, only few most popular doctoral programs, such as Computer Science, were created. Although Russia has the national standards for Software Engineering programs on Bachelor and Master levels, the Doctoral program in Software Engineering is still not developed. Hence, the project provides an opportunity to develop such a program and propose as a national standard.

The concept of software engineering in Russia significantly differs from the SWEBOK. Traditionally, the Russian universities put a strong emphasis on the software development and mathematics. However, several critical areas of software engineering related to management and soft skills are almost neglected. The leading role of the software development was supported by the experts from Russian IT companies during the Panel for National Priorities and Needs in Russia. In contrast, EU professors advocated the importance of software development management, because the ability to organize the efficient software development process contributes more to the economy of the country. Hence, it is impossible to create an effective PhD program in software engineering only by Russian professors. The Russian partners need to take into consideration the experience of the EU universities and the worldwide industry standards such as SWEBOK.

The two-week Russian School was arranged together by South Ural State University and the Ural Federal University in May 2017, with the theme of math and computing foundations of software engineering, and 17 students and 34 staff members participating. This provided an excellent opportunity for participants to learn about subjects where Russian universities are traditionally strong. The students also benefited from access to the university’s distributed computing cluster. Additionally, the school invited experts from abroad to lecture on cryptography and information security. During the school’s staff program section development of Russian software engineering education with SWEBOK was discussed, how Russian universities could open up more to the international scientific community, and how to develop international partnerships in higher education. Correspondingly, two to four students and an equal number of staff from each Russian university have been able to participate to each school abroad. By now over thirty students from Russia have been able to participate in schools abroad.

The research agenda of many Russian universities is outdated due to their isolation from the outside world. Hence, to be able to determine current directions of research in software engineering, the Russian universities need to establish a partnership with the universities outside Russia. The recommendation of the PWs@PhD program for the most appropriate solution is to build a distributed PhD program in software engineering with joint supervision of students by Russian and European professors, such as a dual program

between Saint Petersburg State University and Lappeenranta University of Technology. The Russian School provided networking opportunities both for students and staff, enabling partner agreements, degree opportunities and further development of software engineering education.

B. Jordan Situation

The future development of education in Jordan faces a major challenge in providing curriculum guidance for new and emerging disciplines. These days software engineering is one of the most challenging area of education. The country has a great need in training software developers for both the public sector and companies. Few companies, especially in banking systems like ProgressSoft, are even leaders in their domains as they are the development contractors for the Gulf and the Arab world. Jordan also has a very advanced healthcare systems that is attracting people for from the region. IT experts in healthcare and medical devices technologists are also highly needed.

Currently, only Jordan University has a PhD program in computer science. There are eleven software engineering programs at the bachelor's level and two programs at master's level. Although there is a pool of young talented professors in software engineering that have been trained in USA, Canada, Australia and UK, still the research facilities and practices are missing. In Jordan, there is an independent body called the Accreditation and Quality Assurance Commission for Higher Education Institutions. This commission provides guidance for creating any education program at Jordanian universities [7]. They have already set some preliminary guidelines. An Arabic SWEBOK version is also available as a source of information to further developing these guidelines. While the development of software engineering program has started along the guidelines set by SWEBOK [7], there is a need for increasing educational resources and further development of programs [8].

The two-week long Jordan school was arranged in February 2017 with 15 students and an equal number of staff participating from all partner countries. Three governmental universities from Jordan combined their effort for hosting and managing the School of Jordan: The University of Jordan, Yarmouk University and the Jordan University of Science and Technology. The aim of the Jordan school was to provide visiting students with a deep understanding of new directions in software engineering, including the following: requirement engineering, software engineering design methods, software metrics and measurements, service oriented architecture, applications of behavioral anomaly detection in network security, and human computer interaction. Additionally, staff from other universities contributed to the curriculum of the school, contributing their wide-ranging expertise from topics such as problem-based learning or human factors in software engineering. During the staff section of the program local and visiting professors reviewed the developing field of software engineering education, and discussed local educational goals and methods to reach them. Correspondingly two to three students and an equal number of staff from Jordan have been able to participate to each school abroad.

The practical outcome for students is to develop the capacity of PhDs in selecting an appropriate method or methods for a software development projects at hand and various types of software systems such as safety-safety systems, biometrics-based security systems, or interactive consumer services. The school was organized to be an opportunity for students from Jordan to identify the challenges facing the software engineering research community as well as avenues for research. Moreover, a look at the Jordan education system, which is based on the North American model of higher education, was discussed with the participating students and staff, and compared to the European system.

Discussion between the staff concluded with recommendations that the curriculum development for the SE education in Jordan should follow the guidelines proposed at national level by Higher Education Accreditation Commission (HEAC) in Jordan. It should comply with the international requirements such the ones in IEEE and ACM and initiatives like the SWEBOK [4], [5]. Moreover, as a direct output of the Jordan School, the involvement of students from the Jordanian Universities have increased. The key expected results from the school of Jordan include:

1. Jordan should be able to capture the experiences from the other partners countries
2. Jordan should be able to sign agreements for staff and students exchange with the partners countries
3. Develop joint supervision between the partners countries for the PhDs students registered in Jordanian universities
4. Create opportunities for sabbatical leave of the teaching staff to partner countries.
5. Develop research labs and infrastructures for software engineering education in Jordanian universities and strategic areas for Jordan such public services and healthcare.

VII. Evaluation of Schools

Feedback was gathered from participating students at the end of each school with a survey. In this section, we present quantitative survey evaluations from the schools detailed in sections V and VI, and summarize open feedback gathered from the participants. Some survey items are not available from the first school (Finland), as the survey was improved and made more detailed after the first iteration. Online learning platforms were prototyped and cases where the system was not yet in use are marked with N/A. The survey used a five step Likert scale for the items, with 1 meaning not at all satisfied, 3 moderately satisfied, and 5 extremely satisfied. The survey results are presented in Table 2. The averages shown in the last column are weighted averages, with individual school weight depending on the number of respondents.

TABLE 2. STUDENT SATISFACTION SURVEY RESULTS

	LUT	Aalborg	Jordan	Russia	Average
Overall satisfaction	3.8	4.0	4.0	3.9	3.9
Curriculum and program	N/A	4.3	4.0	3.7	4.0
Online learning platform	N/A	4.4	N/A	4.1	4.3

The overall survey result from participating schools is "very satisfied," with a $\sigma = 0{,}09$ standard deviation between the schools. The activity that was ranked highest in Aalborg University school was academic writing and peer review practice (4.7). In Jordan school the highest ranked activity was company visits (4.9). In Russian school the highest ranked activities were mathematic foundations of software engineering (4.25) and data mining (3.9).

According to open, text-based feedback students preferred team-based activities that were modeled after real academic activities. For example, the academic writing and peer review practice was said to be highly beneficial. Workshops that first had a lecture on a novel research method and then had a laboratory project that was structured to resemble a working research team were also mentioned to be highly beneficial. Overall students wished for even more team-based activities that are modeled after existing academic structures, such as research teamwork, local conferences, and workshops. Lectures and homework were least favored parts in open feedback.

VIII. DISCUSSION

At the time of writing, first four schools have been arranged and networks of cooperation between the organizations have been established. In this section, we discuss initial outcomes and then lessons learned during the first half of the program.

A. Outcomes

The outcome that was fastest to realize was the educational network of schools and the beneficial impact for the participating students. Numerous students from diverse countries have participated in the schools and have benefited from more diverse training by software engineering research experts than they could have accessed by their own. Feedback surveys indicate that the participants are highly satisfied with the PhD training provided, especially with the practical expertise in research methods. Training in academic processes, such as peer review, was also highly valued by the participants.

We have observed the following benefits to the Russian and Jordanian universities:

- Providing opportunities for systematic exposure to diverse PhD education cultures. The presented program offers a unique chance to broaden their knowledge in software engineering while getting a better understanding of research agenda in different groups.
- Increase the attractiveness of the universities through double degree programs at PhD level. The project created opportunities for participating universities to build joint supervision as well dual programs. For example, the case between Saint Petersburg State University and Lappeenranta University of Technology.
- Provide multidisciplinary opportunities for exploring business, technical and human dimensions of software engineering. Participating universities together covers not only the key areas of knowledge in SWEBOK, but also the related ones such as management, cognitive science, mathematics, as well as professional ethics.
- Provide help in developing PhD programs in software engineering together with international partners and co-supervision.

The ultimate goal is to create a self-sustaining, collaborative network of schools. For universities that did not have a PhD in software engineering or have only PhD program in computer science, we aim for the following key results:

- Establishment of the first PhD program in software engineering. This is the aim in Jordan and three of the Russian universities.
- Development of the roadmap for research and education in software engineering.
- Training of current and future members of the academia in software engineering knowledge areas and related disciplines.
- Co-supervision of PhD students with professors from the EU universities.
- Organize industry panels to gain better understanding of the industry needs for software engineering PhD education.

For now, the following key goals have been realized:

- Establishing and operating a high quality educational network for PhD training with observed benefits to the participating students,
- the start of the educational roadmap and providing support, organizational and educational know-how towards establishing the PhD programs,
- first industry panels (e.g. in Jordan), and
- establishing the first co-supervision cases.

B. Lessons learned

The PWs@PhD project has been a large undertaking, and as with all such projects, there have been challenges and successes. The first success was establishing the educational network and providing diverse education from various software engineering experts to a wide range of PhD students. One of the future challenges related to the educational network is making it self-sustaining and making it an attractive alternative to sending individual students abroad. Jordan for example has a practice of sending students to distinguished foreign universities for PhD education in addition to domestic programs. However, one of their national goals is both increasing the number of PhD graduates and establishing a domestic software engineering program. Pooling resources as presented in the PWs@PhD program would allow sustainable development of PhD education, with the host organization and an increased number of students simultaneously benefitting from the resources. Furthermore, the PWs@PhD project allows establishing concrete benefits for the participating students and to create ties between the participating organizations. These can serve as motivating factors and as evidence when it comes the time to dedicate resources for the next set of students. Additionally, some countries have established national PhD training networks, such as the Finnish INFORTE ICT network[3]. INFORTE allows

[3] http://inforte.jyu.fi/about

universities to for example pool resources for inviting distinguished foreign researchers to provide PhD courses in Finland. An international PhD network, such as the PWs@PhD presented in this paper, would be the natural next step.

The second main goal and challenge is establishing cooperation between diverse organizations and by extension, cooperating with the national organizations that direct and supervise academic organizations such as universities. Some of the project goals include making larger organizational changes, such as establishing new PhD programs. This requires the cooperation of university administrations, and in some cases governmental supervisory organizations. To facilitate reaching these goals, the project participants are creating common standards, guidelines, and scientifically rigorous material to establish pathways and to support organizations in reaching these goals. Success has been reached earlier in Finland with the dual degree PhD program with Russia, and the project has initial success in supporting Jordan with their goal of a software engineering PhD program. Such efforts can take long before benefits can be realized, possibly even longer than the duration of the current program, but the initial results in the first half of the project have been promising.

IX. Conclusion

In this paper, we presented the educational program and framework for training PhDs in Software Engineering developed in the Erasmus+ Project PWs@PhD. The project is funded by a grant from the European Commission's Erasmus+ Program. The project involved eleven universities from six countries including Russia and Jordan, plus a network of sixteen partners. The project aims to empower the academic capacity of EU and non-EU countries in educating the next generation of software engineering professors and researchers. The goal was to increase the capacity of universities in providing the basic education for software developers. The program also aims to enhance the capability of universities with limited resources to train highly qualified PhDs by sharing their expertise, research facilities and resources with other universities. It has helped universities such challenges, for example by training students in which the discipline of software engineering was not highly developed, in countries like Jordan and Russia.

Up to now, four schools have been organized (Lappeenranta, Copenhagen, Jordan and Russia). More than 50 PhDs, and 40 professors and teaching staff in total have participated in these schools. More than 60 training activities have been offered to PhDs by professors from the participating universities, leading researchers as well as industry practitioners. Preliminary feedback from all participants confirmed the expected benefits of the project as well as helped to refine the original educational framework. Among others, the project has created a synergy between partners for sharing research facilities while creating joint supervision, laying groundwork for dual programs, and reseach collaboration via projects.

One major character of innovation is related to the fact that the program addresses the current tendency of education as an individualized service. Every student involved in the program can build their own track, selecting the the schools she or he wishes to attend as well as the training activities that are related to her or his interests. They have also access to courses taught by outstanding instructors from all participating universities to supplement the standard curriculum in their respective universities. This project also prepares the participating universities to a smooth transition towards PhD education as a service. The project is paving the road for a new approach for dual degree and co-supervision as well as for sharing of the professors, and the costly research infrastructures required for education.

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References

[1] P. Návrat and M. Bieliková, "Software engineering education: different contexts, similar contents," *ACM SIGCSE Bull.*, vol. 31, no. 2, pp. 55–59, 1999.

[2] B. M. Kehm, "Quality in European higher education: The influence of the Bologna Process," *Change Mag. High. Learn.*, vol. 42, no. 3, pp. 40–46, 2010.

[3] J. Bartelse and J. Huisman, "The Bologna Process," *Glob. Ph Forces Forms Dr. Educ. Worldw.*, pp. 101–113, 2008.

[4] R. J. LeBlanc, A. Sobel, J. L. Diaz-Herrera, T. B. Hilburn, and others, *Software Engineering 2004: Curriculum Guidelines for Undergraduate Degree Programs in Software Engineering*. IEEE Computer Society, 2006.

[5] "SWEBOK V3 • IEEE Computer Society." [Online]. Available: https://www.computer.org/web/swebok/v3. [Accessed: 07-Apr-2016].

[6] G. Taran and M. Rosso-Llopart, "Software Engineering Education in Russia: A Comparative Study of People, Process and Technology a Four Year Perspective," in *Software Engineering Education & Training, 2007. CSEET'07. 20th Conference on*, 2007, pp. 19–28.

[7] F. Al-Zaghoull, A. Hudaib, and M. Ahed, "Software Engineering Education in Jordan," in *6th International Conference on Computer Science and Information Technology (CSIT)*, 2014, pp. 127–132.

[8] S. Hanna, H. Jaber, A. Almasalmeh, and F. A. Jaber, "Reducing the Gap between Software Engineering Curricula and Software Industry in Jordan," *J. Softw. Eng. Appl.*, vol. 7, no. 7, p. 602, 2014.

[9] P. Lažetić, "Managing the Bologna Process at the European Level: institution and actor dynamics," *Eur. J. Educ.*, vol. 45, no. 4, pp. 549–562, 2010.

[10] B. Reinalda and E. Kulesza-Mietkowski, *The Bologna process: Harmonizing Europe's higher education*. Barbara Budrich Opladen, 2005.

[11] P. Bourque, "Contributions to the Maturation of Software Engineering as a Discipline and a Recognised Profession," University of Ulster, 2005.

[12] W. R. Duncan, "A guide to the project management body of knowledge," 1996.

[13] B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, *Taxonomy of educational objectives, handbook I: The cognitive domain*. New York: David McKay Co Inc, 1956.

[14] M. Azuma, F. Coallier, and J. Garbajosa, "How to apply the Bloom taxonomy to software engineering," in *Eleventh Annual International Workshop on Software Technology and Engineering Practice*, 2003, pp. 117–122.

[15] R. R. Peterson, "Twenty-First Century Leadership Challenges," *Eng. Times*, 2005.

[16] I. Askehave, H. L. Prehn, J. Pedersen, and M. T. Pedersen, "PBL Problem Based Learning." Aalborg University, 2015.