SCoPE@Scuola: (In)-formative Paths on Topics Related with High Performance, Parallel and Distributed Computing

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Abstract. The SCoPE@Scuola initiative was born with the aim to inspire curiosity in high school students about High Performance Computing (HPC) and Parallel and Distributed Computing (PDC). The HPC/PDC world could be an interesting matter for students because is a necessary tool to solve challenging problems in science and technology and it provides context where a plenty of knowledge acquired at school can find a real application. In fact, the themes related to HPC/PDC involve a large range of knowledge and skills: from mathematical modelling of problems to algorithm design, from software implementation to design and management of complex computer systems. The initiative, begun at the end of 2014, involved several schools in the Naples (Italy) district, and has also been used for work-based learning activities and projects aimed to avoid students "dropouts". The results collected during all the last years make us hopeful that such initiative could be useful both to increment students awareness about the utility in the real world of all the knowledge acquired at school and to help them in their future educational and/or working choices.

Keywords: Education · Scientific computing
Parallel and Distributed Computing

1 Introduction

As expected by *"Recommendation of the European Parliament and of the Council on key competences for lifelong learning"* [16], nowadays students need to be oriented toward an active participation in building their knowledge with the aim to acquire some key competences (e.g. skills in math, science and technology).

Teachers and students have to build together a path which, starting from the acquisition of specific disciplinary skills and passing through the ability to transfer them into different contexts/fields, finally reaches the target of building a knowledge able to support students as active and responsible citizens during

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their life. Along this path the teachers have to play the role of a guide for students with the aim to increase their awareness and motivation.

The SCoPE@Scuola initiative was created by the Management and Support Team (the authors of this work) of the SCoPE data center at the University of Naples Federico II. We intended to offer to secondary school students the chance to acquire a wider vision on how the use of IT systems allows the solution of challenging problems and the advancement of knowledge in various fields of academic and industrial research.

The SCoPE datacenter [14] is an example of computing resources integrated in international distributed computing infrastructures and usable in various research contexts. The chance to present SCoPE, and all the issues related both to High Performance Computing (HPC) and to Parallel and Distributed Computing (PDC) (outside the academic research environment) represents two significant opportunities for students and teachers: (1) to *"touch"* modern and advanced technologies outside the school context and (2) to develop the "Computational Thinking" attitude [35] by mean of glance on the real world complexity.

The initiative, conceived and designed during 2013, started at the end of 2014 with the involvement of the first "pilot" schools. The related activities include some seminars and different kinds of laboratory experiences. The feedback from students (to date about 400) and their teachers is continuing to confirm the interest in the initiative, as it provides young students with new skills spendable in the short/medium terms (e.g. during stages and final high school exam) and, in the long term, by helping them in their future choice for university courses and job. In fact, the topics associated with HPC/PDC involve a large amount of knowledge areas and skills (from mathematical modelling of problems to algorithm design, from software implementation to design and management of complex computer systems) and can be interdisciplinarily linked to various disciplines at school (from Mathematics to Informatics, from Physics and Earth Science to Biology and Geography).

This work is organised as follows: in Sect. 2 we describe how the initiative fits into the context of the HPC/PDC education, in Sect. 3 we describe the initiative and give details about all the involved *"actors"* and their *"modus operandi"*, in Sect. 4 we give details on how the initiative has been perceived from the students, in Sect. 5 we explain why the initiative can be considered the starting point for work-based learning activities and in Sect. 6 we summarise the contents of the work giving some details about our future activities.

2 Related Works

Much is being done in the international context to strengthen the chance for students to access curricula or contents related with themes of Parallel and Distributed Computing [6]. However, at the moment, in Italy it seems difficult enough to introduce such contents into the school curricula. Nevertheless, in a few years all students will live and work in a world where problems that mankind will have to solve will be more and more complex and will be faced only with

the massive amount of computing power made available by the achieved goal of the *Exascale Computing Project* [10].

The approaches used and the contributions given to initiate students to the HPC/PDC world are many and various: some people have developed tools to help the teaching of parallel programming (i.e., see [25,27,29]), others built experiences on how to iniziate students to parallel programming by using and comparing different paradigms and technologies (i.e., see [4,21,23,33]); some people realized experiences and programs to initiate students in the building-up and management of supercomputing systems (i.e., see [22,30]), others used science demands to motivate the need for the computational simulation (and its related tools) to solve problems of the present (i.e., [28,31,36]).

In this scenario, SCoPE@Scuola is a framework where activities concerning almost all of the above-mentioned themes can be carried out. Such activities can be chosen by the schools that intend to adhere to the initiative on the basis of their needs. Up to now, SCoPE@Scuola doesn't want to be the context where all the above topics are deeply acquired but it intends to play a role in the approach described in [34]: to realize a sort of *"HPC/PDC Immunization"* by giving school students small doses of HPC/PDC themes to help them to feel familiar and therefore not hostile to HPC/PDC world.

3 The Initiative and Its *"Actors"*

Too often, the so-called *"digital natives"* are unaware of the real potential of the many IT resources they access to via the Internet (such as search engines, shared storage spaces, social networks, etc.): few of them wonder what's behind everything they use daily. Even less of them are able to realize how IT resources can be used in finding solutions for problems of everyday's life (such as weather forecasts, mapping and geo localization systems, traceability and security of bank transactions, air traffic logistics management, etc. - i.e., [19,20]).

So, the ideators of SCoPE@Scuola initiative some years ago wondered about the way to motivate young people in studying and in being awareness about technology usage: we were confident that telling students about the HPC/PDC world (the world where we enthusiastically work) could be a way. We have also been driven by the conviction that the HPC/PDC world could be an interesting matter for school students because (1) it is a necessary tool to solve present challenging problems both in science and technology, (2) it involves a large amount of knowledge and skills in an interdisciplinary context, (3) its topics can be linked, using an interdisciplinary approach, to various disciplines at school. We contestually decided to address the initiative to students (and teachers) that are attending (are teaching) the last years of high school and whose studies (teaching) are related with STEM Education [7].

SCoPE@Scuola, inspired by the ancient Chinese saying *"I hear and I forget. I see and I remember. I do and I understand"*, is a "place" conceived both for information and for real training activities: the informative part of this initiative provides two seminars and a guided tour at the SCoPE datacenter, while the training

activities include laboratory experiences focused on technological/scientific topics related to HPC/PDC. The SCoPE@Scuola's implementation protocol (see Subsect. 3.1) outlines all the steps of the interaction between the School Teachers Group and the Academic Team. The activities related with the experiences to be carried out in laboratories are part of the SCoPE@Scuola's portfolio (see Subsect. 3.2).

3.1 SCoPE@Scuola: The Implementation Protocol

During the year 2013, when the initiative was conceived and designed, we worked to identify the set of contents and procedures that represents the SCoPE@Scuola "modus operandi" and constitutes the so called "implementation protocol" of the initiative [18]. The protocol provides the following steps:

Introduction phase

- *The first meeting*: The SCoPE@Scuola team meets school teachers and discuss about a possible set of laboratory activities identifying curricola subjects that might benefit from the experience.
- *The second meeting*: The SCoPE@Scuola team goes to school to meet students and to hold a first seminar on the history of supercomputers and on the role of scientific computing in complex problems solution.

Design phase

- *The third meeting*: The SCoPE@Scuola team and school teachers define together the content and calendar of the laboratory activities.

Realization phase

- *The fourth meeting*: Students and their teachers attend a descriptive seminar on the SCoPE infrastructure and carry out the guided tour to the SCoPE datacenter.
- *The following meetings*: The SCoPE@Scuola team prepares/integrates the material for the laboratory. Students attend the laboratory activities related to the HPC/PDC themes.

The initiative promoters expect to have a quite varied audience for school curricula and students maturity, so in concert with the teachers, they attempt to develop activities with frequent references to what students acquire at school (where possible). All the activity's remaining part, that cannot be referred to curricola, is made enough easy to be understood by students.

Infact, the objective of the initiative is not to make the students able to master complex contents (e.g. advanced mathematical tools) but to help young minds in appreciating the role of each components of science and technology for the solution of complex problems. In particular, we want put a strong emphasis on the role of mathematics as a useful tool because it is perceived by most students as difficult and useless.

3.2 The Portfolio of the Activities

The portfolio for laboratory activities consists of a set of macro assets that allow to explore all the aspects of designing, managing and using computing infrastructures: from the realization of *"homemade"* (or *"schoolmade"*) parallel computer prototypes up to the process that, from the mathematical formalization of the problem, leads to the *"parallel"* software for the "in silico" solution of the problem itself [24]. The portfolio currently includes the following macro assets:

1. *The "Problem solving steps in Scientific Computation" - From problem to software, passing through mathematical and numerical modeling*: How to use the computer to simulate and/or describe physical and natural phenomena (e.g. the simulation of the Tsunami trend).
2. *When HPC becomes necessary because the problem is "too big"*: Implementation of simple parallel algorithms (i.e. the computation of the sum of n numbers, the computation of BLAS operations [3], etc.) and "performance" evaluation of the implemented software when the problem size varies.
3. *A parallel computer "within everyone's reach"*: the realization of a Beowulf cluster [32] - From the installation of the operating system to the benchmarks execution to evaluate the implemented system performance.
4. *Infrastructures and Platforms for Big Data*: Introduction to "Big Data" [26] theme and practice in using Apache Hadoop [8], and related tools (i.e., Apache Hive [9]), to manage and use large amount of data.

Each group of students can be involved in laboratory activities related with one or more themes in one of the above described assets. As described in Subsect. 3.1, all the aspects related with the activities to be performed, are discussed with the student's teachers during the first two phases of the initiative.

Such decision-making process can not ignore issues related to the students knowledge and to the curricula offered in the different schools in order to better choose both the level of in-depth approach to some themes (e.g. the mathematical tools used to describe physical phenomena) and the type of activities (technology- or science- oriented).

3.3 The First Involved Schools: The "Pilot" Schools

In September 2014, after a year of reflection and design, the activity of the SCoPE@Scuola initiative was launched (through the participation at conferences, the production of leaflets and the sending of emails to the School Executives of the High Schools of Naples district). After about a month, a dozen schools had shown interest for the initiative. Among them, three schools decided to join: the **Polo Tecnico "E. Fermi - C.E. Gadda"**, the **Istituto Statale di Istruzione Superiore "A. Serra"** and the **Istituto Tecnico Industriale "A. Righi"**. In the following years, also the **Istituto Tecnico Industriale "A. Volta"** began to participate to the initiative. With all of the above listed schools the collaboration still goes on enriching itself with new contents.

All the above schools have Computer Science curricula of good quality, but very poor was the amount of HPC/PDC-related contents presented in such curricula (just some experiences related with the implementation of *"naif"* parallel algorithms). To date, the total number of students and teachers involved was about 400. All the students attended to the informative sections of the initiative (the seminars on the history of supercomputers and on the SCoPE infrastructure, the guided tour to the SCoPE data center).

Some students (about 40), and their teachers, of the **The Polo Tecnico "E. Fermi - C.E. Gadda"** and the **The Istituto Statale di Istruzione Superiore "A. Serra"** attended to laboratory activities included in the second asset of the portfolio (i.e. 2-*When HPC becomes necessary because the problem is* "too big"). The activities concerned the implementation, execution and performance analysis of simple parallel codes (e.g. the sum of n numbers) on different hardware platforms (multi-core and multi-node architectures). The activities were partially prepared at school. During these activities (of about 5 h), the students used a small set of computational resources of the SCoPE data center: a cluster of 8 nodes with 8 core per node and Infiniband connectivity.

Some students (about 50), and their teachers, of the **The Istituto Tecnico Industriale "A. Righi"** and the **Istituto Tecnico Industriale "A. Volta"** attended to laboratory activities included in the third asset of the portfolio (i.e. 3-*A parallel computer "within everyone's reach"*). The activities concerned the "construction" of a Beowulf cluster for parallel computation. For each school, the activities were carried out in different meetings (3 meetings of about 4 h) during which the following topics were dealt with: the Linux operating system installation and configuration, the network cabling and configuration, the installation and configuration of the Resource Management System, the installation and configuration of software library for Message Passing paradigm (MPI) [13], the execution of parallel software based on the MPI paradigm used to test the developed cluster. The students, during these activities, used *off-the-shelf* hardware (PCs end SOHO network switches) and open-source software as the Torque Resource Management System [15] and the OpenMPI library [1].

During the last school year, the following activities are ongoing with the students of the **Istituto Tecnico Industriale "A. Volta"** and of the **Istituto Statale di Istruzione Superiore "A. Serra"**:

- from the fourth asset of portfolio (i.e. 4-*Infrastructures and Platforms for Big Data*): Introduction to the Big Data theme and practice in using Apache Hadoop and Apache Hive to manage and use large structured databases (about 30 students are involved in about 10 h of activities). The students used a small Hadoop-based infrastructure: a set of 5 * (HDFS DataNode + Yarn NodeManager) services configured on off-the-shelf hardware.
- from the first asset of portfolio (i.e. 1-*The "Problem solving steps in Scientific Computation"*): Seminar on the Problem Solving steps in Tsunami case study and practice in executing basic linear algebra operations using software computational environment as Matlab/Octave [11,12] (about 15 students are involved in about 10 h of activities).

4 Results

At the end of the first year of activity, we have summarised the results of the initiative using data collected through an online survey submitted to participants in anonymous form. The results obtained, and related with about 100 survey completed responses, can be classified in terms of: (1) satisfaction of the initiative, (2) impact of the initiative on awareness of utility, use and structure of supercomputing systems, (3) impact of the initiative on choices related with remodulation of the own training path.

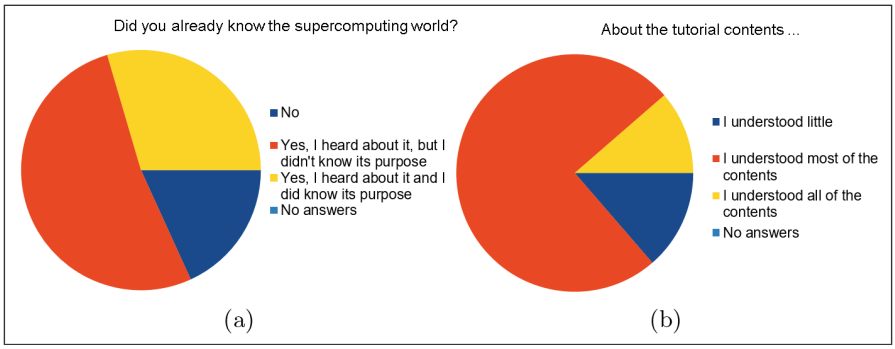

Fig. 1. The previous knowledge of the HPC/PDC world (a) - The level of tutorial comprehension (b)

From the students answers emerges:

- the lack of awareness of the HPC/PDC world before participating in the initiative: only a few students responded that they knew usefulness of the HPC/PDC world before their participation (see Fig. 1(a));
- that the contents presented during the seminars was considered by the students quite understandable (see Fig. 1(b));
- that the contents presented during the tutorial and preferred by the students are related with the most technological and practical aspects: much appreciated was in fact the visit to the SCoPE datacenter and the laboratory activity (see Fig. 2);
- the students said they were significantly interested in the possibility to continue to explore the issues addressed during the initiative. The most preferred topics are related with Computer Science (Computational Science is almost neglected) (see Figs. 3 and 4).

Our survey ended with a question about students desire to take a training/work experience in an environment where issues related to the HPC/PDC world could be tackled: even in this case, the interest expressed by the students was high. Students who have expressed their interest in this kind of experience have also answered the question *"Would you like to be part of the SCoPE data center management team? To deal with what?"*. Here are the students's answers that we prefered:

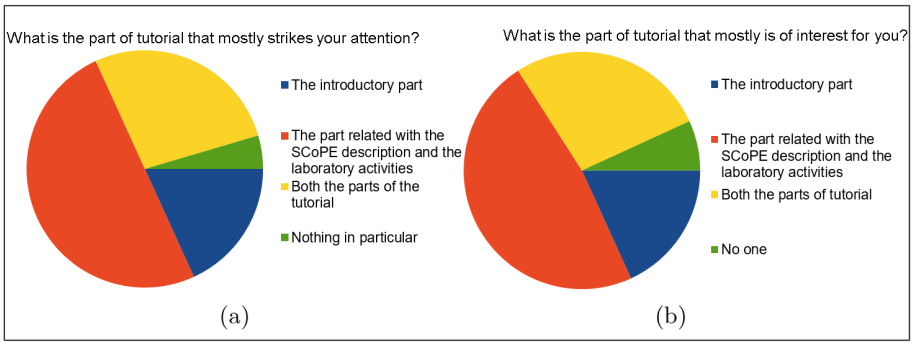

Fig. 2. The part of tutorial that mostly strikes the attention (a) - The part of tutorial that mostly is of interest (b)

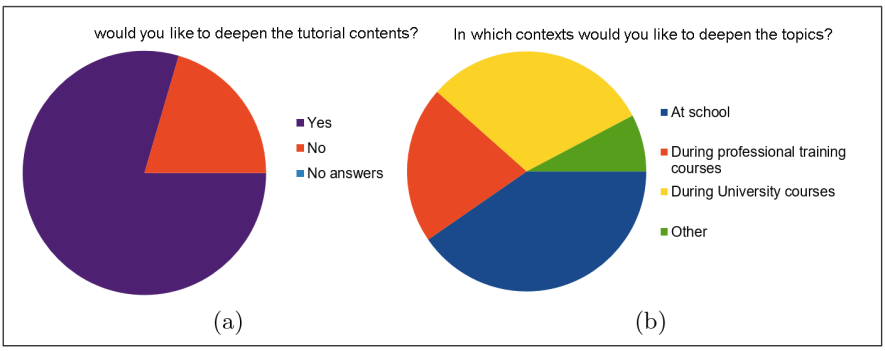

Fig. 3. Level of interest in deepening the contents (a) - Where to deepen the contents (b)

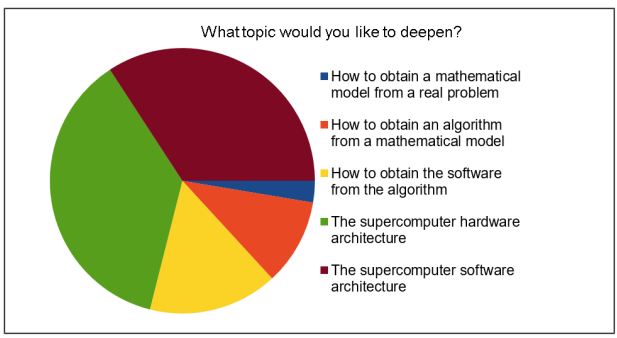

Fig. 4. Interest in deepening the contents: some details

- *"... to divulge knowledge on supercomputers, I would like to help other people know about this world ..."*
- *"... I would like to be able to deepen all the supercomputing system issues with skilled people because I believe that such people have a lot to teach me ..."*

Students also appreciated the initiative because such experience brought them closer to the university environment in a not formal context, allowing them to do (with absolute freedom) any useful questions to satisfy both curiosity on the university context and to ask for information useful to define their future training and working path.

The above-described results merely give an idea on how the students perceived the informative part of the initiative and they confirmed that issues related to HPC/PDC might be of interest to high school students. However, as the initiative is consolidating, we are thinking about the methods to use to evaluate how all the proposed contents have actually been acquired by students. This is a necessary step to remodel both the contents and the modalities by which these are presented also in order to make them not just a one-time extracurricular experience but also an integral part of existing curricula.

5 Other Offered Opportunities

> "... *The dissemination of high quality work-based learning forms is at the heart of the most recent European education and training guidelines and is one of the pillars of the Europe 2020 strategy for smart, sustainable, inclusive growth ...*" [17]

In addition, the Italian Law 107 of July 13, 2015, reiterates the importance of work-based learning - in a mode called *"Alternanza Scuola-Lavoro (aSL)"* - including through internships and quality apprenticeships. The same law enables these activities to be carried out outside the industrial companies in the strict sense provided that the host institutions are able to fulfill the aims of the aSL initiative [2]:

- *"to implement educational and learning methods which systematically combine classroom training with practical experience";*
- *"to enrich the training at school by skills that can also be spent on the labour market";*
- *"to foster the orientation of young people to enhance their personal vocations, interests and individual learning styles".*

The SCoPE@Scuola initiative can be characterised as a suitable context for the aSL activities for students. Therefore, one of the pilot schools decided to start aSL path in the SCoPE@Scuola context to teach students, on the job, how *"to configure and to manage a simple system for parallel computing"*.

With some schools, SCoPE@Scuola was involved in projects aimed to avoid students "dropouts" (e.g., see the "Scuola Viva" Project [5] funded by Campania Italian region). In such context SCoPE@Scuola performed activities which

aims was: (1) to introduce, or to get stronger, students to the *"Computational thinking"* and to the *"coding"* action, (2) to explain how such skills can be used to *"ask"* things with computational capacity to perform useful actions (*"smart object programming"*).

6 Conclusions and Future Work

SCoPE@Scuola is a one-time extracurricular experience in a not formal academic context that provides us the chance to try *"to infect"* some young minds with the virus of passion for HPC/PDC world: the students and the teachers could together know a world that is still too hidden.

Students seem to appreciate all of the content exhibited during meetings, mostly those related with the technological and practical aspects: the structure of computing systems and how to handle and maintain them. They also appreciated the need for parallel computation as the only tool to solve *"the very large"* problems. There is a lot of work to foster knowledge and appreciation of the scientific computation and computational simulation, especially respect to mathematical modelling and numerical aspects, as indispensable tools for solving current and frontier problems. SCoPE@Scuola hopes to have soon an effective role in fostering students appreciation for the themes related with Computational Science.

The main difficulty faced by students is due to the construction of a *"forma mentis"* capable of identifying and integrating different knowledge and skills to solve concrete and complex problems. Often the students have shown that they possess knowledge and skills but they ignore how to spent them in complex and interdisciplinary contexts far from the school ones. SCoPE@Scuola wanted, by a little experience on the field, to provide students and their teachers, a glance on

> *how to solve a (very large) problem by means of powerful computer, using an interdisciplinary approach, in an interdisciplinary context.*

We hope that this glance on the complexity (made of more simple and interconnected pieces) can be effective in generating in many young people what Wing calls *"an attitude"* [35]: knowing how to look at problems using the *"best"* perspective in formulating solutions that are useful also to the others.

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