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Preface

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In Italy there are several physics education research (PER) groups with great and internationally recognized value, contributing to the international PER community with publications in indexed journals and books, participating in prestigious editorial committees, and the boards of important international bodies, like European Physical Society - Physics Education Division (EPS-PED), European Scientific Education Research Association (ESERA), International Physics Education Research Group (GIREP), Multimedia Physics Teaching and Learning (MPTL). One of the 27 prestigious medals of the International Commission on Physics Education (ICPE-IUPAP) was awarded in 2018 to a member of the Italian PER groups. However, this value is poorly exploited and supported in Italian Physics Departments, where the Italian PER community work. As a matter of fact, the Italian PER is funded only with European or regional projects, but not through national funding plans.

During the last EPS International Forum in Paris, a round table was dedicated to Physics Education and the relationship between school and university: two were the Italian invited speakers. I took this opportunity to ask the President of the Italian Physical Society (SIF), Angela Bracco, to support the Italian PER scientific disciplinary sector, named FIS08. She positively reacted by proposing to hold a conference where to discuss our research results, thereby making a selection of contributions to submit to the journal *Il Nuovo Cimento C*, published by SIF.

The twenty active PER groups presented their research approaches and examples during the conference held in Udine on 25-26 November 2022. The editorial board evaluated all the presentations and acted as first reviewers for the selection of the manuscripts. The editorial board prepared an evaluation rubric as well, that has been used by prestigious external reviewers to examine each contributed manuscript. This process has led to the selection and revision of the contributions to be published.

The present volume contains 16 selected research contributions on different research lines, including: content research for the development of educational paths; teaching/learning strategies for conceptual change, for laboratory activities and their integration into teaching/learning paths, for active learning in higher education; the social, epistemological aspect and identity building; teacher education and community building; the contribution of research on history of physics to teaching/learning activities; informal education and inter-institutional collaboration, *e.g.*, among schools, museums, and universities, for physics learning.

In the research line of content research, the Udine Physics Education Research (PER) Unit has presented the results of 30-years long studies, aimed at identifying conceptual learning pathways in physics for students of different ages and for teacher education. This work shows how entangled research methods are carried out to build coherent conceptual thematic learning paths, and connecting research with practice in a wide spectrum of topics and age levels: from primary school to university and teacher education. Four new strategies, integrated in the path proposals, are described in detail. Mainly focused on primary science education, the research of the University of Bolzano PER Unit is characterized by the attempt of integrating the scientific discipline and its didactics with the humanities, the main results being presented especially in terms of prospective teachers' education. One of the three PER Units of the University of Napoli outlines a unified introduction to the general problem of dynamics intended for a high-school students group, with the aim of circumventing the lack of mathematical knowledge with the use of geometric diagrams, a discretized version of the equations of motion and a simplified form of computation and analysis of their solutions. A specific example of content research approach is given by the PER research group of the University of Palermo presenting the design and development of two Teaching-Learning Sequences (TLSs) on surface phenomena in liquids, and the data collection and analysis methods, performed with groups of high-school students. The presentation specifies the conceptual scheme for the "improvement of students' learning", and presents the TLSs phases, that are based on the well-known inquiry- and investigation-based learning approaches, that are science-specific applications of the general idea of active learning. Taking an educational reconstruction of Quantum Mechanics (QM) as a paradigmatic example, the PER Groups of the Universities of Milan and Rome present the following general research lines. The choice is prompted by the fact that, through QM, students can lay out the structure of a new grammar, which is necessary for the presentation in high school of any quantum theory (in particular, Quantum Field Theory). Research-based implementations of the proposal appear to indicate that the introduction of formal aspects of QM in Italian high schools is possible with more than satisfactory learning outcomes. Another contribution in the research line of content research is offered by the PER group at the University of Pavia on the work performed in the past two years, focused on conceptual understanding from a wide perspective, including the design of TLSs, studies on teacher professional development, and conceptual change research.

Quantitative analysis methods and large-scale evaluation tools based on empirical data are discussed by another PER group at the University of Napoli, after a review of the literature on the learning process by means of the Learning Progression Model (LPM). The contribution considered LPM to discuss possible implications for PER and teaching practice.

An epistemological approach to physics education research aimed at aligning physics teaching with the society of acceleration and uncertainty is carried out by the Bologna research unit. This contribution first describes the motivating process, and then refers to selected modules and corresponding design principles, that represent a compass to make the physics epistemology resonate with students' personal processes of sense-making and enacting creative thinking.

Attention to experiments and lab work strategies in different ways is presented by the Trento and Salerno research units. The COSID-20 project of Trento followed different approaches and methods to design a remote physics laboratory: experiments using tools and materials from a specially designed home kit, created and sent to the participants, "kitchen experiments", simulations, experiments pre-recorded by the teacher, remote access laboratories and virtual laboratories, analysing the learning process in the different cases. The Salerno research unit proposes and briefly motivates examples, based on elementary physics principles, of different real-world phenomena, as useful tools in the student “engagement” phase where the Inquiry-Based Learning approach is exploited.

In higher education, we have now to solve the drop-out problem of having large-size classes, and the need to develop competences. The research unit of the Politecnico di Milano carried out a comparative study between a traditional teaching method and an implementation of peer learning into traditional physics lectures, through the use of technology with freshmen. Results proved that active learning work is effective in increasing the students’ final examination pass rate.

How history of physics can contribute in the teaching learning process is the goal of the contributions of the Napoli history-of-physics research group and of the Verona unit, in cooperation with researchers in history of physics from Genova and Torino Universities. The former contribution, from the Napoli unit, presents selected projects carried out in Napoli during recent years, with students of different levels (from high school to university), after adopting well-defined historical paths. Aimed at allowing the involved students to develop appropriate physical reasoning skills, the lines of action encourage the students to: 1) think like the given scientist of the past, who is the subject of the activity, building step by step proper knowledge and reasoning; 2) work like that scientist, performing the original experiments; 3) deduce the subject matter just like that scientist did; 4) present the results of their activity to other students (including physics demonstrations) and to the general public. Attention is in the key role that the history of physics can play in promoting scientific understanding at a deep level, even without requiring particular mathematical knowledge or advanced preparation. The second contribution focuses on the discovery of the electron. Even a mere cursory perusal of secondary school and university physics textbooks reveals indeed that two experiments are usually addressed: Sir J. J. Thomson’s measurement of the e/m ratio in 1897 and, with a 14-year jump, R. Millikan’s measurement of the charge of the electron in 1911. In order to stress the physics education significance of this historical case study, this 14-year gap is reconstructed through a close analysis of the original documents. This analysis reveals that the discovery of the electron case study has all the ingredients to become an important educational tool to promote among teachers (in-service and pre-service) and students a better understanding about the nature of science and its complexity.

The research line on teacher education is present in a number of contributions, but the contribution of the Padova research unit describes the CoLLabora project, involving the first implementation of the research-based structured model aimed at finding and supporting evidence of a research-based in-service program for physics teachers, and at improving their use of the laboratory. The contribution also presents two case studies outlining selected research lines and the developed “teacher training cascade”.

Based on informal and non-formal learning, the educational strategies developed by the Cagliari research unit are in the framework of a constructivist approach. Examples of the proposed educational activities are implemented by discussing related features and potential roles in facilitating science and physics instruction. For almost twenty years, the Physics History Group, the University History Museum and the Physics Museum of the Pavia University have been elaborating a year-long shared project with schools of all levels. This has led to the development of strong, long-lasting relationships between the participants and a community of practice. New pathways are sought to allow all participants to live meaningful experiences, to bring the school closer to cultural heritage and to the local community, and to foster in the learners the development of a scientific identity. Everyone worked alongside, sharing stories, experiences, competencies, intellectual pleasure, codified knowledge and tacit knowledge, in a non-judging environment. Qualitative research results have emerged from the students’ work and from the open interviews with the teachers. The differentiated research lines and results obtained in the examples here presented highlight the great richness of the Italian research in physics education: a wealth that has played the function of mutual fertilization of the research itself, and that offers as well many contributions for teacher education and the improvement of practice in teaching at all levels. We hope that this special issue will be useful to practice in the field, as well as to the research itself, and that it will contribute to a better understanding of physics education research and to its support within the physics community.