MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(4), em2243
ISSN:1305-8223 (online)
OPEN ACCESS Interview https://doi.org/10.29333/ejmste/13031

An interview with Marisa Michelini: IUPAP-ICPE medal, professor of physics-education research at Udine University, GIREP President

Maria Luisa Marilù Chiofalo [1,2*], Marisa Michelini [3]

[1] Department of Physics "Enrico Fermi", Pisa, University of Pisa, ITALY
[2] INFN - Pisa section, ITALY
[3] Department of Mathematics and Physics, Università di Udine, ITALY

Received 14 January 2023 ▪ Accepted 28 February 2023

Abstract

The present interview was conceived and realized for the occasion of the first 45 years of endless Physics Education Research activity of Professor Marisa Michelini, a lifetime dedicated to innovate teaching and learning environments to all degrees of instruction, and to design institutional architectures, where rooting these innovations. The interview structure is inspired to the nature of scientific thinking, i.e. inducing more general understanding from concrete observations, in two manners. First, the interview focuses on (ten) topics drawing from three box-cases about physics education research and teachers education in scientific areas: innovations in teaching/learning environments; theoretical and methodological frameworks; and strategies and tools for institutional cooperation between schools and governing bodies to urge policy making. Each topic is introduced by observations, from which the interview questions are induced. Second, each question draws from Marisa Michelini's contributions, to touch core topics at the heart of science education, science and society.

Keywords: physics education research, teachers education, strategies for teachers professional development

INTRODUCTION

The present interview was conceived and realized for the occasion of the first 45 years of endless Physics Education Research activity of Professor Marisa Michelini, a lifetime dedicated to innovate teaching and learning environments to all degrees of instruction, and to design institutional architectures, where these innovations can be rooted in.

Recipient of the 2018 IUPAP-ICPE Medal and of the Italian Physical Society Award for Physics Education in 1998, Marisa Michelini is author of more than 660 articles and books with peer review pioneering research in Physics Education (PER) and Teacher Education in scientific areas (TERS), and responsible for the whole section on content research of the most recent edition of the prestigious International Handbook in Physics Education Research (Taşar and Heron, 2023), published every ten years. Numbers and stamps often risk to offer barely informative views of careers, whereas – as a humankind – we deeply need authoritative and inspiring ones instead. In this perspective, we can paint Marisa Michelini's lifetime as a living intertwined fabric serving as a connector: (i) between different disciplines, (ii) between concreteness and abstraction, and (iii) among individuals of one same scientific community and between different communities, among institutions. This intertwined fabric is not, once again, an abstract construction, but the concrete ground where education can nurture from, its intrinsic transformative nature coming to existence and functioning as one primary resource for humankind: in fact, the only ever-lasting primary resource to invent the resources we are still missing and struggle to catch, in order to tackle the ever-new daily challenges we have to face. In the rest of the present introduction, the three cases (i)-(iii) above are traced, serving as a connecting background for the conversation that follows.

(i) Scientifically born as a condensed-matter experimental physicist with diversified disciplinary

✉ marilu.chiofalo@unipi.it **(*Correspondence)** ✉ marisa.michelini@uniud.it

specializations i.e., besides PER, in chemistry and computer science, Marisa Michelini has well beforehand pioneered the idea that ICT tools, games, as well as conceptual and virtual experimental labs, can be powerful allies to overcome scientific challenges in conveying contents during scientific learning and creative open-problem solving, in both contexts of formal and non-formal (or informal) education.

(ii) Scientific thinking is a powerful two-ways connector between concreteness and abstraction. In this perspective, the practical innovations pioneered by Marisa Michelini hinge in, and are in fact framed by, substantial theoretical and methodological developments, implementations, and testing: the Model of Educational Reconstruction (MER) is one significant example, as a research approach for vertical-path proposals, with the associated Design-Based Research (DBR) encompassing tools and methods for analysing learning processes and building formal thinking in science education. These (and others) theoretical frameworks and methodological tools have been implemented and tested thoroughly, though in these times of the exploding field of quantum technology we wish to highlight the special focus that Marisa Michelini has given to the teaching/learning of modern physics.

(iii) The worth of academic knowledge, no matter whether theoretical or experimental, is based on the extent to which it serves to unveil the deepest mysteries of humankind, and to transfer to daily society life contents and tools useful to empower required transformations. In this perspective, Marisa Michelini's lifetime has witnessed tremendous efforts in designing strategies, models, and tools for (both school and university) teacher education and professional development, both pre-service and in-service; in creating models for institutional cooperation among schools and governing bodies; and in steady and tireless action of advising, guiding, and urging policy makers about the corresponding transformations.

The structure of the interview is inspired to the very same nature of scientific thinking, i.e. inducing more general understanding from concrete observations, in two manners. First, the interview focuses on (ten) topics from the three box-cases (i)-(iii) above, each topic being introduced by observations from which are induced the questions that Marisa Michelini answers to. Second, each question draws from Marisa Michelini's contributions, to touch core topics at the heart of science education and thus of science and society.

PROFESSOR MICHELINI'S VITA

Marisa Michelini is full time Professor of Physics Education in the Department of Mathematics and Physics of the University of Udine. In her long career at the University of Udine, professor Michelini has been since 1994 Delegate of the different Rectors for Didactics, Guidance, Innovation, School-University relationships,

Figure 1. Marisa Michelini (Source: IUPAP-medal ceremony at the International Conference GIREP-ICPE-EPS-MPTL, Budapest 2019)

and more recently for the activities related to the Consortium of Universities GEO, which she chairs since 2014. In 1992 she founded the Physics Education Research Unit (URDF), for which she is up to now responsible of. She was Head of the Physics Department for 7 years (2004-2010) and director of the university School of specialization for secondary-school teachers (SSIS) of the Udine University (2003-2007), and responsible for the related Physics, Mathematics and Computer Science (FIM) section (2001-2008). In 2006 she has founded the IDIFO project within the National Plan for Scientific degrees (PLS), aimed at fostering innovation by means of physics education research and involving 20 Italian universities. She has conducted six biannual national Masters for teachers professional development, eight full immersion summer schools for secondary-school talented students and six full immersion for in-service teachers at the national level. In the international context, since 2012 she is President of International Research Group on Physics Education (GIREP), since 2016 board member of the Physics Education Division Section of the European Physical Society (EPS), since 2014 board member of Multimedia Physics Teaching Learning (MPTL), since 2019 consultant of CERN-Education.

Her research activity is on electrical transport properties of thin films (1985-2000) and on physics education, which she steadily carried out during her whole career on a number of research lines, as follows.

(A) Innovative physics education paths on modern physics and prototypes for lab experiments, in particular: (A1) educational paths on Moessbauer effect, Hall effect, electrical, optical and thermal properties of solids (resistivity, reflectivity, polarization, heat conduction), quantum physics, superconductivity; (A2) original prototypes for hardware and software systems to carry out experiments on electrical, thermal, and optical phenomena (Termocrono, Fente, Lucegrafo and H & R), and dynamic modelling (Sigma, SEQU).

(B) Research and development on multimedia of: (B1) innovative curriculum units in the field of mechanics, thermodynamics, electrical transport properties in solids, quantum optics and physics for secondary schools and universities; (B2) Learning Objects for blended e-learning activities.

(C) Initial education and professional development of teachers on classical and modern physics, and guidance.

(D) Collaboration models between school and university, in particular the research model CRUS.

(E) Informal education: development of an exhibition for 650 hands-on simple experiments, and in particular (E1) low-cost experiments and relative activities, (E2) rubric for informal explorations, (E3) conceptual laboratories (CLOE-Conceptual Labs for Operational Exploration), (E4) multimedia software support.

(F) Problem solving test with the PSO method.

(G) Computer-based interactive environments for learning and BYOD. (H) Learning progression and building of formal thinking in science education.

She has been the principal investigator of two European (EU) funded projects and responsible for the Italian Unit of five EU-funded projects, besides 32 national and 15 regional projects, yet in physics education research.

She has been awarded with the 1989 Italian Physical Society Education Award for the Exhibit *Games Experiments Ideas*, and the 2018 IUPAP-ICPE International Award for physics education research.

Her research activity is documented by more than 660 peer-review selected publications in books and journals.

THE CONVERSATION

MC:

Professor Marisa Michelini, I would like to thank you beforehand for this time that we are going to live together, where we are going to trace your fundamental contributions to Physics Education Research (PER) back during more than 45 years of activity.

Inspiration is an essential ingredient for long-lasting transformations, and it more easily comes through real-life story-tellings. A first warm-up question is thus

What did lead you to choose Physics Education Research as your scientific field?

Marisa:

A number of very different persons and contexts made me curious and passionate on Physics Education Research. In 1977 I had a small office room in Palazzo Estense of the University of Modena, opposite to another equally small, where in the evening there periodically were Cesare Bonacini and Francesco Dalla Valle. In successive periods, they have been presidents of the Italian Association for Physics Teaching (AIF) and promoters of many qualified activities in the field, including the journal Physics in the School. They involved me in their activities and invited me to the AIF Congresses, where I became aware of a number of innovative proposals in physics education, especially about physics experiments in school. In 1979 Arturo Loria asked me to go and help him to organize the International Conference on Education for Physics Teaching at the ICTP in Trieste. I found myself facing what at the time I felt to be huge tasks: the management of an educational laboratory alongside the Nuffield one of Wenham and Scoffield, and a thematic contribution on the teaching of quantum mechanics in a world of great experts in educational research. Among them were George Marx from the Budapest University, Uri Haber Shaim from MIT, Uri Ganiel from Israel, Brian Woolnough, Paul Black, John Ogborn from UK, Peter Kennedy from Edinburgh University, the Swedish group with Borg Svenson and Cedric Linder, the Finnish group with Ahonen Arto and Taajamo Matti from Jarvaskila, the German group with Hans Jodl, Brian Davis, Hans Fischer, Helmut Michelskis and many others. In fact, I have a good reason to especially mention Eric Rogers, who had recently published his wonderful book Physics for Inquiring Mind. He was running a workshop parallel to the Conference that my lab was part of. Every day early in the morning, he was meeting me in the lab. With his friendly smile, he was used to recommend Wenham and Scoffield to help me. Then, he was asking me one of his intriguing questions with little hand-made sketches, promising to come back at lunch time to get the answer. Every day, however, John Ogborn was reaching the laboratory at 11 am to see if we needed help, and stepping to discuss the Rogers questions. Thus, at lunch Eric Rogers was always finding those questions answered in a multi-perspective and rich manner. That's why he gave me an autographed copy of his book, with his wishes for a wonderful career in physics education research. During those ten days I learned so much, framing the roots of the different existing directions of education research, and becoming passionate about it. Drafting the proceedings with Barbara Pecori completed my first overall picture of physics education research. I was then involved and taught a lot in GIREP congresses which I began to attend, agreeing to act as rapporteur in the workshops organized by leaders in international research. No less important were the teaching experience in the first Italian National Advanced Course for teachers professional development at the University of Modena (1976), and the participation in the meetings of the National Research Group in Physics Education of CNR with Giulio Cortini, Ettore Pancini, Matilde Vicentini, Paolo Guidoni, Lella Tommasini and others, in which they were discussing directions and methods of research. Overall then, the experiences in AIF and in the world of didactic research contributed to build a clear vision of the research landscape in this field at both national and international levels. At the same time, they increased my passion for physics education research. I soon became aware that I could have conducted this research in Italy as an activity additional to other studies.

MC:

Our (local and global) society is characterised by a high degree of complexity for its social and cultural traits. Using the word economy by its etymon, that is the management of home resources, we are every day faced with the challenge of preserving the environmental resources that we are given by Nature, recovering the existing but hidden resources i.e. those that society segregates because they are not recognized as valuable, and inventing the missing resources i.e. those we need to solve novel problems. Under this perspective, while disciplinary knowledge is certainly very much needed to handle the increasing technicalities that complexity requires, it also must necessarily oriented to become cultural objects. The underlying idea is that disciplinary knowledge be produced and not reproduced, in fact to be reshaped in creative and ever-evolving forms, to interpret, get to know, and understand the world. We assist instead to a systematic and artificial splitting of culture into humanistic and scientific. An even more dramatic splitting occurs at the level of disciplines, while education evolves from being centred on the unique person's intelligence(s) at the kindergarten, to be discipline-centred at higher instruction levels up to college. The most common result is a separation between science and culture and between science and technology: we prepare citizens with highly specialized technical skills but evanescent culture.

In your opinion, which challenges (in terms of criticality and opportunities) are the most relevant for a massive and widespread education to scientific thinking? In particular, what about physics: why is physics so hard to be learned, or else what are we making wrong while teaching it (at all instruction levels)? With all this splitting going on, it looks like daily reality has been somehow disconnected from either contents and/or teaching/learning: the question then arises on what do we mean for "contents" and what for "teaching/learning".

Marisa:

It is now universally recognized by indisputable evidence of didactic research that learning is a process of appropriation. For physics, this involves the conceptual change from common-sense interpretative to scientific ideas of phenomena. This process has to be conducted to build the learners' physics identity, by offering fundamental experiences in the epistemological nature of the discipline. Tools, methods and contents must be developed together, to offer appropriation of the physics: that is, to offer the scientific identity that provides competence in managing new interpretative situations. Critical reasoning of interpretative hypotheses, formal and informal multi-representations, alongside with iconographic, graphic and mathematical, are part of scientific language to be integrated with the natural one in its same evolution. This contains new meanings such as those of physical quantities like force or energy, having a role in the context of theories, or of models like waves and point mass, with their respective potentialities and limitations. In particular, analogies and simplifications must be accompanied by the awareness of their role and limits. Reductionism for the purpose of simplification has to be, in my opinion, avoided because it destroys the potential of critical interpretative thinking, which physics is based on.

The way physics has been taught so far has not been based on such awareness. This has produced in young people a decreased interest for this matter and the scientific illiteracy reported by the PISA investigations. As a result, a vicious cycle is being created, which negatively affects the representation that young people and society have about physics. There are many reasons for this. However, the lack of a basic scientific culture among citizens, and the modest attention paid so far to teachers education, are not of secondary importance in this context.

We are paying the lack of attention to the didactic aspects of physics teaching and learning. We have made glaring mistakes, which heavily weigh on the representation of the discipline. We have been teaching physics in the same manner in all schools and at all levels: privileging results over processes, and using physical models in ideal abstract contexts, without producing experience of how they become useful for the interpretation of phenomena in the real world. The process of formalization has almost never been made explicit. Approximations and simplifications are declared, but poorly justified. Physics is then experienced as a discipline, which speaks of things that do not exist (the point mass, the perfect gas, etc.), through difficult laws, which one does not know when to use. The beauty, usefulness and broad use of the discipline do not emerge in physics courses. In addition, physics is taught too late (after acquiring mathematical competence). Finally, the vast and demanding work of didactic innovation, based on education research, still has too little impact to overcome the conceptual learning problems.

Thus, these are a number of preliminary and main objectives to produce appreciation of the physics contribution: recognizing the value of scientific culture for all citizens, and including adequate scientific education in school curricula. They are achievable if one can rely on good professional preparation of motivated teachers at all school levels. Particularly important and delicate is the education of teachers for 3-12 years-old children, which preludes to the introduction of a valid scientific teaching for everyone. The first steps are: improving how we teach physics, and conduct professional education of teachers. Three important aspects are to be taken into account: the interpretative ideas and the spontaneous ways of looking; the experimental work integrated into the interpretative one (hands-on/minds-on); the need to innovate tools and methods, so that students can master their achievements and learn by appropriating concepts and contents.

The main approaches followed so far must be changed accordingly. First, scientific education must begin very early in kindergarten and primary school, together with the first experiences of observation and representation of the surrounding world. Second, physics must be taught in a differentiated way according to the context where it is proposed, overcoming the lazy self-referential habit of reproducing the same basic and preparatory modules. Third, learning must be produced, which is not the transmission of structured notions and answers to non-posed questions: personal involvement in the conceptual appropriation of content is the condition for educational success. Fourth, learning environments should be built, in which the personalization of the learning path is achieved through personal learning trajectories in an active process based on individual responsibility. Finally and in particular, teachers education based on educational research should be ensured in a targeted manner, especially for kindergarten and primary school teachers.

MC:

All this leads us to the importance of Physics Education Research. So, time has come to observe that a lot of confusion hovers on the term. We might state that PER is connected pedagogical research on teaching, psychology of individual learning, sociological studies on how educational and school activities should be organized, up to how to story-tell the content of disciplinary research as e.g. in outreach and dissemination activities. However, PER is often confused with one or more of the above.

What is PER and why is it important? In your opinion, to which extent this recognition problem occurs, where it originates from, is it a criticality or an opportunity?

Marisa:

Research in physics education should not be confused or replaced with pedagogical research on teaching, psychological research on individual learning, sociological studies on the organization of school activities. It is linked to the construction of skills to produce specific learnings of a disciplinary nature (learning of Subject Matter). Why focus on content instead of just methods? Learning is subject-related and this cannot be forgotten.

The main lines of research at international level concern: the curriculum, its structure, management, and content; the methods, i.e. the role of group work, homework, information and communication technologies (ICT); cognitive aspects; social aspects; conceptual aspects related to the discipline and conceptual development (i.e. the role of context, representation, reasoning, narration, analogies, metaphors); learning paths (strategies, approaches, spontaneous models); new experiments, prototyping and multimedia products; models and methods for the professional development of teachers.

In particular, content research is motivated by the fact that the teaching of a discipline is and produces scientific education (as remarked by Nidderer, see below). Learning is linked to specific content. Teaching practice must be improved through research. Research on content structure must be promoted, also for teachers training research.

At the International School of ESERA for PhD students in physics teaching in Udine, already in 2010 Hans Niedderer highlighted the generally recognized needs to be explored: teaching/learning processes for new topics; conceptual learning and laboratory activity; learning in relation to strategies, tools and methods; conceptual change.

It is clear that all this is specific to the discipline and that pedagogical models and strategies, by their general nature, require to identify how they are implemented and operational in the disciplinary context. Similarly, it is essential to analyse reasoning lines to identify coherent productive paths of disciplinary learning, let for example think to the teaching of quantum mechanics. Thus, specific research activities should be related to determine objectives and contexts (and relationships among them), identify student conceptions, develop tests on specific contents, look for the role of approaches, concepts, contexts, motivations on learning specific topics, and finally identify conceptual profiles, pathways and learning processes of students reasoning (i.e. static and dynamic conceptual and interpretative models).

Research in physics education has its own specificity. This cannot be substituted by siding a pedagogical to a disciplinary competence. The integration of pedagogical and subject-related competences implies a relevant transformation of the structured contents of the subject itself. In fact, specific content reconstruction for educational purposes implies research on conceptual knots and learning difficulties, after identifying the foundational nuclei of the given topic, as well as effective strategies and examples in relation to the discipline nature. Learning of the latter is not a heap of notions and formulas, but the deep appropriation of a fertile way of analysing and interpreting the world.

MC:

Your answer about the importance of PER is definitely convincing. It is then time to highlight the most exciting and relevant challenges that the PER community currently faces.

Let us start from contents. Your research activity has historically started (we are talking about the years 1983-1994) with experimental studies of electronic transport of metals in thin films, of semiconductors and of superconductors. Interestingly enough, you have dedicated also part of your PER studies to the same topic. It now happens that condensed-matter physics is at the heart of modern physics, coming at centre stage for two main reasons. One is the tremendous boost of quantum science and technology research, requiring the training of a minimally prepared workforce in a revolutionary job market. Second, the microscopic world cannot be seen with our eyes. This brings a conceptual limitation while teaching elementary quantum physics, but also a fantastic educational opportunity. Indeed, the models we build up work to bridge experimental data to knowledge and we can more easily intertwine physics, technology, and research to interpretative models. (This goes back to the first question, in fact.). However, if modern physics and elementary physics have tiny room in school curricula, condensed-matter physics in a modern sense has no room at all.

Is this one challenging content for PER and, if it is, to which extent? With a fully wide-open sight, which content frontiers is PER currently moving with?

Marisa:

Condensed-matter physics is one of the great areas of research in physics and I agree that today it is increasingly important. However, it is not present in the teaching of pre-university physics, neither are its nature, role and importance perceived. This happens at all levels: teaching programmes and textbooks rarely contain condensed-matter elements and even more rarely a minimally coherent treatment of at least one of its main themes. An exception is the electrical conduction of solids, sometimes dealt with by a coherent treatment, especially in schools with a technical orientation. It is necessary to change the programs setting: the latter is too often performed according to the historical evolution of ideas, with detriment of the consistency and coherence of theories. This is particularly evident for quantum mechanics, that in most practices and textbooks is addressed as a story-telling of the issues addressed and, at best, as an historical reconstruction of crucial experiments like the photoelectric, Compton, Frank and Hertz, Zeeman effects, etc. Sometimes it starts from the emission of radiation with the laws of Kirchoff and with Planck's solution, in which the explaining hypotheses are presented as ingenious surprises in an otherwise superficial context awareness. Optical spectroscopy in descriptive terms is the basis to discuss the Bohr atom with

Sommerfeld revisions, without discussing the limit of the spatial representation of the atom. Generations of students I asked, "You think the atom exists, what is the proof?" have recalled Democritus or the Brownian motion, totally unable to give evidence of this firm belief. Whole generations have no idea of quantum physics as a theory and only know the history of quantization: quantum physics! As a result, they also get the wrong idea of what a theory is in physics, and in particular they lose the sense of coherence of theoretical physics. Students should live similar experiences to those of the theoretical physicists and address the fundamentals of theory.

As you know, we developed a specific path proposal on the fundamental concepts of quantum physics, that is based on optical polarization and is now widely experimented with 17-19 years old students (more than 120 classes of about 20 students each). Fortunately, we are no longer the only ones: PER is offering several proposals in this direction, based on a two-state approach with spin, quantum wells or even with Feymann paths. We hope that practice will soon take advantage of these resources. Textbooks are essential for the dissemination of new approaches, but too little is said about publishers. Perhaps the publishers too little look at educational research results and researchers are not paying attention in contributing to textbooks. Certainly, if the programs will be updated by the Ministries of Education, this would be a nice push to the process. Updating the programs on quantum mechanics however, would not solve the problem of the gap in education to condensed-matter physics, which researchers in the field and in PER do not care much. This happens despite the fact that the discussion on the macro-micro relationship in physical models is a widely addressed problem in PER. The main attention is to electrical and thermal phenomena.

In 1996 I organized in Udine a GIREP Congress on the teaching of condensed matter physics: despite the 300 participants with as many contributions, a line of research on the subject was not active, apart from the individual issues I mentioned above.

The contribution I have made in my research in physics teaching has been oriented to build and experiment proposals on the analysis techniques that are integrated into the current curriculum. The study of the electrical transport properties of metals, semiconductors and superconductors, in which I have worked with an experimental approach for years, has allowed me to introduce a series of educational proposals, highlighting three aspects that I consider important: (i) how a number of analysis techniques are used to characterize a system; (ii) how each analysis technique is based on semi-classical interpretations that use principles of energy conservation and momentum, and each proposal is a possible context to introduce, apply and analyse them; (iii) how interpretative models of the theory integrate themselves with the experimental data, discussing the meaning of data fitting rather than interpolation. The proposals concerned heat conduction, resistivity and Hall measurements for electrical transport properties, time-resolved reflectivity, Rutherford backscattering spectroscopy accompanied by an educational contribution on the concept of cross section and, more recently, optical and gamma spectroscopy. The identified learning paths were accompanied by experimental activities, for which ad hoc hardware and software prototypes were developed for measurements suited to an educational laboratory. Alongside this perspective, however, we need to propose a vertical path that starts in kindergarten and primary school, with the study of materials properties. This should be developed by addressing those aspects of the theory that allow us to understand for example the relationship between electrical and optical properties, as well as thermal. In so doing, we can build the coherent framework of interpretations without limiting oneself to the mechanistic vision of models on the structure of matter.

MC:

Challenging contents call for a challenge in methods. You have pioneered a number of ideas which have become paradigms in PER. One example are the idea that Information and Communication Technologies (ICT), interactive tools and games, conceptual and virtual online experimental labs, can be powerful in sustaining analogic innovations in teaching/learning processes. A second example is the development of the Model of Educational Reconstruction (MER) and associated Design-Based Research (DBR) as a consistent and coherent approach to the design of vertical-path proposals.

Would you elaborate for us on the motivations and the how-to of these two specific methodological challenges, that is ICT-like tools and games on the one side, and MER and DBR on the other? With a fully wide-open sight, which methodological frontiers is PER currently moving with?

Marisa:

A game is an activity, a development gym. As Vygotsky says, there is a huge influence of the playful moment in a person development. Game rules, which cannot miss to relate to the affective sphere, become a goal (work) and a learning. The playful moment has a transitional nature between the concreteness of the action on the one side, and the thinking as totally detached from the action on the other: that is, the abstraction ability. The playful context of the game offers an opportunity to decontextualize the school activity. The game definition motivates and activates personal learning processes, and realizes the connection with playful-symbolic skills. The transition from action to abstraction is a process within the individual, which enables him/her to develop logical memory and abstract thinking, spontaneously freeing themself from reality. Perception is the trigger to act for this transition. Playing increases the degree of awareness related to their actions. The rules make the game increasingly attractive. In the game activity, each experience receives something from those who have preceded it and modifies in some way those that will follow, as Dewey points out (Dewey, 1939). The recreational activity allows to experiment various frames and/or living conditions without conditioning, and to experience different styles. The individual thus broadens their vision of the world and "experiences the way of thinking about the universe". It is crucial for science education to explore different worlds and different ways of looking at them with hypotheses, which in turn create other worlds (models) for their interpretation. Playing to understand phenomena, reasoning and not just manipulating, offers access to the knowledge tools and to metacognition, constitutes a training ground for critical reasoning in the scientific interpretive process, and supports the understanding of how physics operates. Information Communication Technologies play an even more important role, offering multiple opportunities for teaching and new opportunities for learning, including: (i) facilitations in calculating and visualizing; (ii) tools and contexts that allow the student to operate as a scientist, digitally collect data in experiments, process them with different facilities, discuss and compare or model them at a distance, or yet test hypotheses with algorithmic models; (iii) carry out experiments otherwise not feasible without sensors, as for example in remote places, for long times, or to collect many data; (iv) allow simulations that explore the rules of the physical world or visualize effects of given conditions, offering multiple exploratory experiences of ideas and realities to form a global vision of processes; (v) tools to compare ideas via virtual boards or web platforms, with multiple functions to integrate calculus tools, video and dialogues. Overall, ICTs have indeed expanded the potential of active learning, especially in science. Of course, it is crucial that they are used to expand the learning objectives and not just to perform in a facilitated manner what has always been done.

The Model of Educational Reconstruction (MER) and the Design Based Research (DBR) are instead didactic research modalities. MER is the theoretical framework of content research for the study of educational paths and DBR is the cyclical mode of research, which the implemented paths are validated with. The methodological frontiers of PER are as many as the different and previously outlined directions of research. They are also very different from each other. Examples are: research and development of materials, tools and multimedia prototypes; development of educational paths; conceptual change; representations for learning; motivation, creativity, and scientific identity. While each of these research directions comes with its own tools and methodologies, they all share qualitative and quantitative analysis methods with tests, interviews, tutorials, videos, often combined together in the same investigation.

MC:

We have already introduced quantum science and technology, as an emergent theme in the second quantum revolution era. The European Union via the Quantum Flagship dedicated initiative Quantum Technology Education (QTEdu) coordination and support action is addressing consistent efforts to design a competence framework as a reference in the process of building up a suited ecosystem able to uplift the level of citizens' culture on the subject and prepare a workforce, thereby addressing students and teachers to all instruction degrees, companies in specific or connected sectors who need employers retraining, decision makers and general public. Similar programs are being initiated in the United States, India, China, and many more countries. Xillions of dollars are being invested by public bodies and companies in these efforts. You have pioneered countless ideas – in terms of contents and methods – about teaching/learning quantum mechanics, and therefore are a privileged observer of this global movement of terrific proportions.

Would you remind us about the results achieved so far by the PER community and yours personally, which you consider most valuable? Quantum technologies are often being exploited as a context to effectively engage learners and support teaching/learning environments: how do you evaluate this approach? Efforts are numerous in outreaching citizens and general public on quantum technologies and, necessarily, on the foundational concepts of quantum mechanics they hinge on: do you think that quantum physics outreach and PER can help each other in pursuing there corresponding goals? In particular, can there be an intersection ground of content and methodology research that can qualify the outreach and make PER more well-known and popular? More in general, where do you see that the PER community is moving towards, in this specific but wide and timely challenge?

Marisa:

The PER community on quantum mechanics (QM) has produced two types of results: (1) identification of specific learning difficulties and related, specific, proposals to overcome them, and (2) development of educational paths with their design, implementation and validation on the foundations of QM. Our results, which are most consolidated and widely experienced (1298 students of 44 classes from 12 different cities, not only Italian), taught us that good learning outcomes are obtained if the design, while hinging on the QM foundational core, aims at making students work like theoretical physicists. In particular, this means that they can start from simple experiments, then link personal with disciplinary epistemologies without reductionism, and introduce the necessary formalism (in our case in the context of polarization, where the two-dimensional vector algebra can be adopted). In so doing, students can focus on the disciplinary core, using representative iconographic methods for the formalization process, while being offered gyms to explore ideas with tutorials, interactive simulations and games. A recent review of QM approaches is published in Michelini M, Stefanel A, (Michelini and Stefanel, 2021). As in all the proposals that have been developed so far, there is no focus on education to quantum technologies.

In the last two years, much work has been done to develop approaches to educational frameworks for quantum technologies: we need to wait some time before this research produces evidences. Also, in the two QTEdu pilot projects which we have contributed to, interesting results have emerged, though work needs to be performed to validate them.

MC:

We have discussed the crucial importance of moving from the school of knowledge to the school of competences and intelligences, from the disciplinary contents in syllabi to a unified design of vertical curricula, from sequential teaching of single disciplines and matters to a teaching/learning process able to engage teachers and learners. One building block, in fact a pillar, of this ambitious program is the training and professional development of teachers. However, a number of problems comes to play here. The combination of pedagogical and disciplinary (or non-pedagogical) competences is often far to be even acceptable, with K6 educators feeling uncomfortable in designing scientific-like educational activities and university professors easily failing to promote and enhance students' talents, especially when unconventional.

What is the state of the art of the research efforts for teacher education (pre-service and in-service training and professional development), under both content-like and methodological perspectives? Which are the most critical and promising challenges that PER needs to face?

Marisa:

Extensive research literature has shown that professional teaching competence should be considered the most important, characteristic, and specific aspect in education and how it determines learning improvement for students, via renewing the actually implemented school curricula and introducing didactic and methodological innovation also based on research results. For this reason, in the last 30 years teachers education has attracted much interest at international level. A lot of work has been produced, including EU guidelines and projects that have accompanied the increasingly numerous researches. Shulman (Shulman, 1989 and 1987) has introduced the seminal idea of Pedagogical Content Knowledge (PCK) and posed the problem of the role of disciplinary content in teachers education, in particular of the research in content education, with corresponding resources and processes. More than 3,000 literature articles have been published today on teachers education. At European level for example, different extensive studies and projects have been carried out (EUPEN, STEPS, ROSE, TIMSS, HOPE), involving more than 70 universities in different Countries, mainly after the 2000 resolution of all European Ministers with sharp indications, see e.g. the Green Paper on Teacher Education in EU, Buckberger et al. (Buckberger, 2000). GIREP has dedicated to this topic whole congresses (Barcelona, 2000; Udine 2003; Malte 2000 and Malta 2001), sessions in other congresses (Reims 2010, San Sebastian 2017), and in the World Conference on Physics Education (Istanbul 2012, Sao Paolo 2016, Hanoi 2020). The state of the art is very rich in data on experimentation, proposals and materials. The critical points are the strong inhomogeneity, differentiation of the teachers education programmes in the different countries, and the often too fragmentary research on specific aspects.

Three most important challenges are still in the field: Which should be an effective teachers education path for a lifelong professional development? How to guarantee a research-based education? How to realize the collaboration between school and university?

MC:

We thus see that we are dealing with a paradigmatically complex system: a sort of chain with highly entangled and intertwined rings. Universities train future teachers and potentially future policy makers in local and national governing bodies, contributing to the governance of the school and university system. University academicians are beforehand trained in the instruction system from kindergarten to high schools and university. The educational places are experienced and lived by almost the entirety of the population (sooner or later), and interacts with all sorts of public and private stakeholders, besides trade unions. They represent the place where individuals grow up and acquire their competences, evolving through continuous transformations: by definition, a place where conflicts are vital and essential to the place functions. This is therefore a quite complex ecosystem, where even a tiny change requires a global vision and a coordinated and coherent action plan affecting every single part of the whole ecosystem, not to speak about epic transformations. The actions must necessarily involve a combination of individual and community empowerment, organizational design and, overall, consistent financial resources.

The following is a set of questions to the Marisa head of GEO (Italian University Consortium on Young Education and Guidance) and pillar of numerous strategic committees of the Italian Ministry of Education aimed at reforming the school system and curricula. How to design and how to make such a complex governance system at work? Imagine that you can design from scratch the whole system, which would be its essential traits? Second, one question to the President of the International Research Group in Physics Education (GIREP) since 2012, to the board member of the Physics Education Division of the European Physical Society and of the International Committee of American Association for Physics Teaching: which are the differences and commonalities – if any - among different countries, and what can we mutually learn from them? Finally, one question to the scientific leader of a number of European PER projects: do you think that there might be a European governance system, and that this might help?

Marisa:

It is a very difficult and very simple question at the same time. Worldwide research results lead to a set of shared directions. Governments, however, move in different ways, especially in the field of education and of teachers education. What is worse is that policy choices are rarely based on reliable research consultations. We would need an international cooperation policy, and for us within Europe to start with. A cooperation of governments on scientific education is relevant as much as that on economic matters. I see this path as much hard as it is necessary, since for example countries like Germany and the USA are federated and have different internal educational systems. In Italy, the most advanced teachers training project, introduced in 2000 and in fact internationally recognized, was suspended without prior evaluation because of a change of government. Since then, there has been an ordeal in the implementation of different models, even without evaluation. The situation is now disastrous for what concerns the development of teachers competences in schools. Our national Master IDIFO for teachers has evidence of teachers' needs, which indeed correspond to the main listed actions and goals in the guidelines of the afore-mentioned 2000 Green Paper.

Since 2000, in Italy GEO has been the interlocutor of the Conference of Rectors of Italian Universities, for the development of suited universities strategies. Here, university stakeholders could compare experiences and discuss with experts, to identify a core of shared ideas, which actions in differentiated contexts could be based on. This has produced a growth of the whole system, already just because of the discussions developed about the comparison on guidance, tutoring, university teaching and teachers training. The proposed actions have been collected in reference volumes, then published on the GEO website www.geo.uniud.it. The improvement of university teaching is now carefully studied with its multidimensional nature. This includes the management of facilities and services, the relationship with the territory, as well as internationalization, and the training of university teachers.

GIREP is very active in the research on teacher training and, as I said, has dedicated since 2000 a number of conference and seminar activities exploring the research viewpoint. I am also pleased to recall that, by statute, one GIREP vice-president comes from the teachers (in addition to academic) world: the collaboration between university and school is for us a basis for research, proposing with the teachers a research-based professional competence.

As to the hardest challenge, I think that we have to promote science education for kindergarten and primary-school teachers. I personally studied, implemented and consolidated a model based on four levels of actions: (1) metacultural, in which research-based educational paths on different topics are examined and discussed under the different perspectives of scientific content, and of pedagogical and operative approaches; (2) experiential, in which primary teachers live via tutorials the same experience they should offer children on given topics; (3) planning, in which primary teachers individually design a formative intervention module, discuss in groups and then in plenary sessions with all colleagues, and revise the module brought in class; (4) situated, in which primary teachers prepare the teaching materials, implement the activity with the children of a given class, and analyse the learning with educational research methods.

MC:

This is a question to the Marisa who – as it emerges from the question and answers shared so far - has been working hard to connect everything everyone everywhere: different disciplines (you are specialized in condensed matter, computer science, PER, chemistry, and what else not), concreteness and abstraction, many individuals in one same scientific community, diverse communities, different institutions, academia and society. This manner of yours, shaped on the importance of experience, of the design of paths leading to results, on connecting persons and things, is symbolically typical of women's way. A number of society-driven factors certainly favour instead males' ways, equally and diversely valuable at the same time. However, in the absence of appropriate empowerment, this unbalance engenders a vicious cycle via stereotypes, the way formal learning and research environments are organized and what they value most, especially in academia, not to speak about role models. We all know that academia too often works in mostly hierarchical manner, appears as a plastic representation of static and incommunicable compartments going down to the size of a disciplinary field and then to the atomistic reduction to single research groups, and suffers from an evaluation system that weights scientific value with all sorts of numerologies.

Do you believe there is a female way of learning, conducting research, leading projects and institutional bodies? Is there a gender issue in academia, e.g. in studies and careers? Most importantly, do you think that there is a gender dimension in PER, across the various topics we have discussed above? Finally, did you have other women as inspiring and role models, and – in case – how they have been important to you?

Marisa:

The question of gender and science is still a big problem, based on stereotypes, as well as different prejudices and representations of society. I could directly experience this during my research in condensed matter physics. It is perhaps less evident in physics education research, only because there are more women researchers following this career, especially in Anglo-Saxon countries.

Yes, of course there is a female way of learning, conducting research, leading projects and institutional bodies! As researchers in PER, we have evidence of a personal, individual way of building physical identity: personal epistemologies evolve with learning according to personal trajectories.

Even more than a gender issue, in PER there is a question of careers: depending on the countries, but unfortunately in many of them, PER is little valued among colleagues of disciplinary physics areas, and mostly unknown by colleagues of psychological and sociological pedagogical areas. In the USA and the Northern-European countries (like Germany, Denmark, Sweden, Finland) there are well-funded research institutes and universities, professorships and numerous PhDs, which guarantee an academic PER community of recognized scientific value.

I am pleased to mention great women I have met and whom I have had the privilege of working with. I provide a few different examples, to start with. First of all Lillian McDermott from Washington University in Seattle, the founder of the Inquiry Based Learning. Her books are translated into 15 languages and have been inspiring physics teaching/learning processes everywhere, also in universities (and in all USA universities), and many PER researchers worldwide. McDermott's work has been recognized by several awards, among which the 1990 AAPT - Robert A. Millikan Lecture Award, the 2000 Archie Mahan Prize of the Optical Society of America (OSA), the 2000 Education Research Achievement Award of the Council of Scientific Society Presidents (CSSP), the 2002 - Oersted Medal, the 2003 - ICPE Medal, the 2013 - Melba Phillips Award in 2013, the 2014 - Lecture Award of the University of Washington, and the 2015 - GIREP gold international medal.

Laurence Viennot from Paris 7, as well awarded with the ICPE medal, who founded new research perspectives on learning processes, looking at critical details in phenomena analysis of learners, and introducing the critical thinking in teacher explanation, just to mention some of her breakthroughs.

Eugenia Etkina from Rutgers University, who founded the ISLE method to build and evaluate the experimental basis of physics identity in students and teachers. I'm still excited by the ceremony where she received the Millikan Medal at the AAPT Conference at Minnesota University where, at the end of her talk, a theatre of over 1000 colleagues stood up to pay her tribute. Last year she gave us an invited talk at the GIREP Congress.

I like to remember three Italian PER women scientists, who enjoyed wide international recognition: Matilde Vicentini Missoni from Rome, Elena Sassi from Naples and Rosa Maria Sperandeo from Palermo. I would love to talk about their contribution in thermodynamics, in the use of ICT for learning and for statistical physics, as well as in the design and implementation of educational courses.

MC:

In this journey, we have touched upon a number of achievements of yours, they being about contents, methods, or – even more importantly – manner of working at them.

In the spirit of provide the readers with an inspirational interview, I feel urged to ask which achievement of yours, you are most proud of? Which is the craziest scientific dream of yours, no matter whether you could make it true or not?

Marisa:

I recently addressed the issue of the best outcome at a national research meeting and I could not choose between the following three: the research approach in the construction of didactic paths on modern physics and the development of multimedia prototypes to be integrated in the proposals of educational paths; the CLOE strategy of active learning even in non-formal contexts; and the MEPS method for teachers education. I am sorry! but in the promo are also others, perhaps.

The craziest dream is a new curriculum that integrates condensed matter physics and quantum physics in kindergarten.

MC:

We have now come to the end of this exciting journey across your first 45 years (since 1977) of tireless and relentless scientific life in PER. One last question (for now) is undeniable at this stage.

What is the future that you see for PER, and which will be your contributions to it in the next 45 years to come?

Marisa:

Physics has made a fundamental contribution to all other sciences and to society. In spite of the difficulties to be understood and the disappointments, I have the hope that the world will gradually understand the great value of education, of the solid foundation of scientific culture for citizens, and of the essential efforts that PER performs to pursue this goal also by means of teachers education at all levels.

Funding: No funding source is reported for this study.

Ethical statement: This work does not involve content that requires approval from an ethics committee.

Declaration of interest: No conflict of interest is declared by authors.

REFERENCES

Buchberger, F., Campos B. P., Kallos D., & Stephenson J. (2000). *Green Paper on teacher education in Europe*. Thematic Network on Teacher Education in Europe, Umea Universitaet.

Chiofalo, M., Giudici, C., & Gardner, H. (2022). An interview with Howard Gardner: John H. and Elisabeth A. Hobbs research professor of cognition and education at the Harvard Graduate School of Education. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(6), em2112 https://doi.org/10.29333/ejmste/12035

Dewey, J. (1939). *Experience and Nature*, New York [code B945.D43 E8 1958; ID OL6251590M]. http://links.jstor.org/sici?sici=0013-189X%28198602%2915%3A2%3C4%3ATWUKGI%3E2.0.CO%3B2-X

Michelini, M., & Stefanel, A. (2021). Approaches on T/L quantum Physics from PER Literature. In Jarosievitz, B., & Sukosd, C. (Eds.). *Teaching-Learning Contemporary Physics, Challanges in Physics Education*. Springer Nature, Switzerland. https://doi.org/10.1007/978-3-030-78720-2_1

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-22. https://doi.org/10.17763/haer.57.1.j463w79r56455411

Shulman, L. S. (1989). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4-14. https://doi.org/10.3102/0013189X015002004

Taşar, M. F., & Heron, P. (Eds.). (2023, in press). *International handbook in physics education research*, AIP Pub. https://www.ijpce.org/index.php/IHPER

APPENDIX

Marisa Michelini Selected Publications

Books and books editing

Beltrame, P., & Michelini, M. (Eds.). (2010). *Il supervisore di tirocinio: conduttore di un racconto e promotore di innovazione, dedicato a Loredana Cicuttini* [The internship supervisor: Presenter of a story and promoter of innovation, dedicated to Loredana Cicuttini]. LithoStampa - Pasian di Prato (Udine).

Bonetta, G., Luzzatto, G., Michelini, M., & Pieri M. T. (Eds.). (2002). *Università e formazione degli insegnanti: non si parte da zero* [Universities and teacher training: Not starting from scratch], Concured, Forum, Udine.

Burra, G. S., Murillo, C. J., Michelini, M., & Perea, C. (Eds.). (2021). *Fundamental physics and physics education research*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-52923-9

Corbo, F., Michelini, M., & Udricchio, A. (Eds.). (2019). *Innovazione della Didattica Universitaria e strategie degli Atenei italiani* [Innovation of university teaching and strategies of Italian universities]. Universià degli studi A Moro: Bari.

De Toni, A., & Michelini, M. (Eds.). (2019). *L'Innovazione Didattica tra Scuola e Università: attuazione di 80 progetti all'Università di Udine* [Educational innovation between school and university: Implementation of 80 projects at the University of Udine]. Cleup: Padova.

Denardo G., Michelini M., & Pugliese, S. (Eds.). (1995). *Teaching the science of condensed matter and new materials.* GIREP-ICPE Pre-Conference Book, Udine. http://www.fisica.uniud.it/URDF/libri/pdf/06IlSupervisoreDiTirocinio.pdf

Kaminski, W., & Michelini, M. (Eds.).(2010). *Selected paper books of the International Conference GIREP-ICPE-MPTL*, Reims 22-27 August 2010, Udine: Lithostampa. http://www.fisica.uniud.it/URDF/libri/pdf/08Teaching.pdf

Michelini, M. (Ed.). (2004). *Quality development in the teacher education and training*. Selected papers in Girep book, Forum, Udine.

Michelini, M. (Ed.). (2010). *La Fisica a Udine. Dedicato a Flavio Waldner* [Physics in Udine. Dedicated to Flavio Waldner]. Lithostampa, Pasian di Prato (Udine).

Michelini, M. (Ed.). (2018). *Riflessioni sull'Innovazione Didattica Universitaria* [Reflections on university teaching innovation]. Forum: Udine.

Michelini, M., & Cobal, M. (Eds.). (2002). *Developing formal thinking in physics*. Girep book of selected contributions, Forum, Udine.

Michelini, M., & Moschetta, C. (2001). *Borse di Ricerca per Insegnanti: coniugare pratica didattica e ricerca* [Research scholarships for teachers: Combining teaching practice and research], NUSU, 2, p.36.

Michelini, M., & Strassoldo, M. (Eds.). (1999). *Modelli e Strumenti per l'Orientamento Universitario, in una struttura territoriale di orientamento* [Models and tools for university orientation, in a territorial orientation structure], CRUI - Università di Udine, Forum, Udine.

Michelini, M., Lambourne, R., & Mathelisch, L. (Eds.). (2010). *Multimedia in Physics Teaching and Learning, Selected Paper from the 14th MPTL Workshop (Udine 2009).* SIF, Bologna and in *Il Nuovo Cimento*, 33 C, 3. https://doi.org/10.13932/ncc/i2010-10620-3

Pospiech, G., Michelini. M., & Bat-Sheva, E. (Eds.). (2019). *Mathematics in physics education*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-04627-9

Sokołowska, D., & Michelini, M. (Eds.). (2018). The role of laboratory work in improving physics teaching and learning. Springer, Cham. https://doi.org/10.1007/978-3-319-96184-2_2

Book chapters

Buongiorno, D., & Michelini, M. (2020). Research-based innovation in introductory physics course for biotechnology students. In J. Guisasola, & K. Zuza (Eds.), *Research and Innovation in Physics Education: Two Sides of the Same Coin. Challenges in Physics Education*. Springer, Cham. https://doi.org/10.1007/978-3-030-51182-1_14

Buongiorno, D., & Michelini, M. (2021). Research-based path proposal on optical spectroscopy in secondary school. In B. G. Sidharth, J. Carnicer, M. Michelini, & C. Perea (Eds.), *Fundamental physics and physics education research* (pp. 239-250). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-52923-9

Buongiorno, D., Evans, R. H., Faletic, S., Guisasola, J., Heron, P., Michelini, M., Planinsic, G., Sarriugarte, P., Stefanel, A., & Zuza, K. (2021). Discipline-based educational research to improve active learning at university. In O. Levrini, G. Tasquier, T. G. Amin, L. Branchetti, & M. Levin (Eds), *Engaging with contemporary challenges through science education research: Contributions from science education research* (vol. 9). Springer, Cham. https://doi.org/10.1007/978-3-030-74490-8_24

Ghirardi, G. C., Grassi, R., & Michelini, M., (1996). A fundamental concept in quantum theory: The superposition principle. In *Thinking physics for teaching* (pp. 329). Aster, Plenum Publishing Corporation. https://doi.org/10.1007/978-1-4615-1921-8_26

Michelini, M. (2010). Building bridges between common sense ideas and a physics description of phenomena to develop formal thinking. In L. Menabue, & G. Santoro (Eds.), *New trends in science and technology education: Selected papers* (Vol. 1, pp. 257-274). CLUEB, Bologna.

Michelini, M. (2020). Dialogue on primary, secondary and university pre-service teacher education in physics. In J. Guisasola, & K. Zuza (Eds.), *Research and innovation in physics education: Two sides of the same coin: Challenges in physics education*. Springer, Cham. https://doi.org/10.1007/978-3-030-51182-1_3

Michelini, M. (2021). Innovation of curriculum and frontiers of fundamental physics in secondary school: Research-based proposals. In G. S. Burra, J. C. Murillo, M. Michelini, & C. Perea (Eds.), *Fundamental physics and physics education research* (pp. 101-116). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-52923-9

Michelini, M., & Mossenta, A. (2014). An experimental approach of nodes towards the electric potential for students and teachers. In G. S. Burra, M. Michelini, & L. Santi (Eds.), *Frontiers of fundamental physics and physics education research*: *Book of selected papers presented in the International Symposium Frontiers of Fundamental Physics* (12th edn, pp. 461-470). Springer, Cham. https://doi.org/10.1007/978-3-319-00297-2_47

Michelini, M., & Stefanel, A. (2022). Quantum mechanics in teaching and learning physics: Research-based educational paths for secondary school. In E. McLoughlin, & J. Guisasola (Eds.), *Connecting research in physics education with teacher education 3*. ICPE Book, International Commission on Physics Education.

Michelini, M., & Stefanel, A. (2021). Approaches on T/L quantum physics from PER literature. In B. Jarosievitz, & C. Sukosd (Eds.), *Teaching-learning contemporary physics: Challanges in physics education*. Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-78720-2_1

Sassi, E., & Michelini, M. (2014). Physics Teachers' Education (PTE): Problems and challenges. In G. S. Burra, M. Michelini, & L. Santi (Eds.), *Frontiers of fundamental physics and physics education research*: *Book of selected papers presented in the International Symposium Frontiers of Fundamental Physics* (12th edn, pp. pp. 41-54). Springer, Cham. https://doi.org/10.1007/978-3-319-00297-2_4

Research articles

Battauz, M., Gori, E., Michelini, M., Pospiech, G., & Stefanel, A. (2017). Rasch analysis of the HOPE-SSQ questionnaire. *Academic Journal of Science.* http://hdl.handle.net/11390/1107305

Bondani, M., Chiofalo, M.L., Ercolessi, E., Macchiavello, C., Malgieri, M., Michelini, M., Mishina, O., Onorato, P., Pallotta, F., Satanassi, S., Stefanel, A., Sutrini, C., Testa, I., & Zuccarini, G. (2022). Introducing Quantum technologies at secondary school level: Challenges and potential impact of an online extracurricular course. *Physics 2022, 4*(4), 1150-1167. https://doi.org/10.3390/physics4040075

Bozzo, G., Michelini, M., Bonanno, A., & Stefanel, A. (2022). Atwood's machine and electromagnetic induction: A real quantitative experiment to analyze students' ways of reasoning. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(2), em2077. https://doi.org/10.29333/ejmste/11567

Buongiorno, D., & Michelini, M. (2017). Optical spectroscopy for biotechnlogy students. *Nuovo Cimento C-Colloquia and Communications in Physics, 40C,* 106.

Buongiorno, D., & Michelini, M. (2021). Experimental use of mobile apps in physics education. *AAPT, New Horizons in Teaching Science, 99*(Suppl 1). https://cab.unime.it/journals/index.php/AAPP/issue/view/Vol99_Supplement1

Calore, G., Loria, A., Mazzega, E., Michelini, M., Sconza, A., & Torzo, G. (1990). An undergraduate laboratory mossbauer apparatus. *European Journal of Physics, 11*(6), 343-351. https://doi.org/10.1088/0143-0807/11/6/006

Chiofalo, M. L., Foti, C., Michelini, M., Santi, L., & Stefanel, A. (2022). Games for teaching/learning quantum mechanics: A pilot study with high-school students, *Education Sciences, 12*(7), 446. https://doi.org/10.3390/educsci12070446

Colonnese, D., Heron, P., Michelini, M., & Stefanel, A. (2012). A vertical pathway for the teaching and learning of energy, Review of science. *Mathematics And ICT Education, 6*(1), 21-50.

Corni, F., & Michelini, M. (2006). The Gibbs phase rule: An experimental path for its recognition and application. *European Journal of Physics, 27*(4), 793-804. https://doi.org/10.1088/0143-0807/27/4/011

Corni, F., & Michelini, M. (2018). A didactic proposal about Rutherford backscattering spectrometry with theoretic, experimental, simulation and application activities. *European Journal of Physics, 39*, 015501. https://doi.org/10.1088/1361-6404/aa9053

Debowska, E., Girwidz, R., Greczylo, T., Kohnle, A., Mason, B., Mathelitsch, L., Melder, T., Michelini, M., Ruddock, I., & Silva, J. (2013). Report and recommendations on multimedia materials for teaching and learning electricity and magnetism. *European Journal of Physics, 34*, L47–L54. https://doi.org/10.1088/0143-0807/34/3/L47

Francaviglia, M., Lorenzi, M. G., Michelini, M., Santi, L., & Stefanel, A. (2012). Teachers facing conceptual nodes of quantum mechanics. *Aplimat - Journal of Applied Mathematics, 5.*

Girwidz, R., Thoms, L.-J., Pol, H., López, V., Michelini, M., Stefanel, A., Greczyło, T., Müller, A., Gregorcic, B., & Hömöstrei, M. (2019). Physics teaching and learning with multimedia applications: a review of teacher-oriented literature in 34 local language journals from 2006 to 2015. *International Journal of Science Education, 41*(9), 1181-1206. https://doi.org/10.1080/09500693.2019.1597313

Mason, B., Debowska, E., Arpornthip, T., Girwidz, R., Greczylo, T., Kohnle, A., Melder, T., Michelini, M., Santi, L., & Silva, J. (2015). Report and recommendations on multimedia materials for teaching and learning quantum physics. *Il Nuovo Cimento, 38 C*, 105-116.

Michelini, M. (2018). Labs in building a modern physics way of thinking. In D. Sokołowska, & M. Michelini (Eds.), *The role of laboratory work in improving physics teaching and learning* (pp. 15-33). Springer, Cham. https://doi.org/10.1007/978-3-319-96184-2_2

Michelini, M., & Mossenta, A. (2007). The construction of a coherent interpretation of electrostatic interactions in the context of training teacher. *Il Nuovo Cimento, 122 B*, 797-812. https://doi.org/10.1393/ncb/i2008-10416-y

Michelini, M., & Stefanel, A. (2015). Research based activities in teacher professional development on optics. *Il Nuovo Cimento 38 C,* 105-126.

Michelini, M., & Vercellati, S. (2012). Pupils explore magnetic and electromagnetic phenomena in CLOE labs. *Latin-American Journal of Physics Education, 6*(Suppl. I), 10-15.

Michelini, M., & Viola, R. (2011). Research-oriented training for Italian teachers involved in European MOSEM Project. Communications: SIF Congress 2009. *Il Nuovo Cimento, 34*(5), 255-275.

Michelini, M., Ragazzon, R., Santi, L., & Stefanel, A. (2004). Discussion of a didactical proposal on quantum mechanics with secondary school students. *Il Nuovo Cimento, 27C*(5), 555-567.

Michelini, M., Santi, L., & Stefanel, A. (2013). E-learning in teacher professional development in innovation and formative guidance on modern physics: The case of IDIFO Master's Programs. *Journal of e-Learning and Knowledge Society, 9*(2), 43-75.

Zuza, K., Guisasola, J., Michelini, M., & Santi, L. (2012). Rethinking Faraday's law for teaching motional electromotive force. *European Journal of Physics, 33*, 397-406. https://doi.org/10.1088/0143-0807/33/2/397

https://www.ejmste.com