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Principles and Equations of Physics: a multidisciplinary laboratory

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Principles and Equations of Physics: a multidisciplinary laboratory

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Abstract. In the last two academical years, as part of the Italian Ministry plan PLS – "Piano Lauree Scientifiche" (Scientific Degree Plan), two courses for high school students and teachers consisting in some interdisciplinary and transversal online meetings have been proposed. They regarded the three principles of dynamics, the law of universal gravitation and Maxwell's equations. "Variations" around these topics were also presented – of historical, philosophical and also of musical nature – to make the cultural setting of what has been discussed deeper and make it meaningful in the present. At the end of each course, students produced a video of few minutes with a personal reworking and rethinking of the meaning of one of the topics discussed.

1. Excusatio non petita
This paper is written in a highly unusual form for a scientific work. However, the choice was conscious, deliberate, and due to the desire to present the results and describe the initiative in a way similar (as approach) to that of the contents covered.

2. Introduction
Understanding and discussing the meaning of basic principles and important equations of physics is fundamental in learning the discipline. But equations and principles express their meaning only within a formal theory. The work here presented is intended to be a description of a didactic approach aimed at presenting the conceptual and formal structure of Newton's dynamics and Maxwell's electromagnetism by framing them in a particularly vast cultural environment. In fact, our starting point is that, in order to construct a significant approach to teaching physics, we have to previously choose a reference theory with its logical-formal structure, to both frame the interpretation of phenomena and understand their meaning, and to bring out the notion of reality implied [1,2].

On the other hand, it is difficult to separate the formal structure of a theory from the cultural context in which it was formulated, and, even if its conceptual structure is substantially supranational and independent of more typically local situations [3,4], nevertheless we believe that the intertwines with the interpretation of the world given by other disciplines and the emotional feelings one can perceive through them can greatly help the contextualization and appropriation of physical concepts.

The aim of the project here described was to provide students with orientation opportunities and help them grasp the charm and the creative and exciting aspects of physics in a surprising scientifichumanistic cultural territory that identifies the scientific theme as a complex path of a logical, historical, philosophical, musical, literary structure that is part of the process of cultural development of mankind.

3. Conceptual landscape

Human history can be seen as the history of the representations of the world that women/men have made, of the place they have reserved in it, and of the changes they have made to it.

Two million years ago a particular type of hominid, probably living in Africa, that evolution would have transformed into the modern man we know today, began to build simple tools to be able to hunt his prey. Precisely because of this drive to build, we could say that engineering is the oldest of human activities. The representation that man had of the world at that time is probably unknown, but it must have been at least sufficient to identify prey and dangers and to be able to pick edible herbs and fruits. The perceptive organs of the primitive hominid had, in fact, developed over hundreds of thousands of years and had become suitable for this purpose. In another two million years they developed further and eventually became ours. But, still today,

> the performance provided by our cognitive apparatus does not differ from what a primitive and uncultured hunter of seals and whales knows about the essence of his prey [...]. However, the little that the organization of our sensory organs and our nervous system has allowed us to know has been experienced throughout the ages. Within its limits we can rely on it! [...] It is quite obvious [however] that the existent has innumerable other faces which, however, [...] are not of vital importance for us. [5].

Over time, the skills of this hominid have increased, and so it has been for more than twenty thousand years that man has been using bows and arrows for hunting and for personal defence. Mankind has been using fire since then, but we had to wait a little longer to get the ability to light it at will. This fact was so important that it was passed down from generations to generations. In Greece, for example, it gave rise to the myth of Prometheus who gave man writing, mathematics, knowledge of nature, and the relieve of fatigue by the use of technology. While in Persia fire was adored by the followers of Zoroaster who were said to keep the first fire lit by man.

More or less simultaneously with the invention of bows and arrows, about seventeen thousand years ago, numerous cave paintings were drawn, such as those of the Altamira Caves in Spain, a true form of art, perhaps religious. Most probably, however, the first drawings are even older; they are around thirty centuries old. They provide us with the first evident signs of a willingness to communicate the representation of the world that existed at the time.

More or less in 6,000 BC, in Mesopotamia, agriculture was born, and, after another three thousand years, also the wheel was invented. Man has been using the wheel for more than five thousand years and for a very long time he has also known how to build wonderful buildings: the pyramids have been imposing themselves on the desert for four millennia, and even the Roman aqueducts are more than two thousand years old. The practice and experience accumulated over the centuries have given architects and engineers the ability to design ever more beautiful and more functional structures such as, for example, the elegant and resistant pointed arches, which have allowed the construction of masterpieces such as the gothic cathedrals. Superb statues have adorned temples and palaces around the world for millennia.

Writing might be dated back to the Sumerians in the middle of the fourth millennium BC. Even before writing, poetry was born: in fact, the first forms of poetry were, probably, essentially oral, like the ancient songs of the peasants, and the tales of storytellers like those that Homer later wrote down. Music accompanies poetry from the very beginning and traces of musical writing date back at least to the times of the Greek poet Pindar, in the fifth century BC.

But let us now come to science. Natural observations of the stars and the changings due to the seasons have been carried out by men from every region of the Earth, for many tens of centuries; and it was precisely these observations, together with the development of suitable tools and utensils, which allowed men to navigate the seas and meet different cultures, each of which had its palaces, its streets, its bridges, its religious buildings.

Mathematics was born perhaps even before writing, and documents of Egyptian mathematics can be dated to 2,000 BC (for example, the famous Moscow Mathematical Papyrus was transcribed before 1,850 BC). Tradition sees Thales as the first mathematician in the modern sense of the term: we are in the sixth century BC.

Western philosophy was also born in the same period, hundreds of years before the Christian era. Philosophers have been investigating the nature and psyche of man for tens of centuries; they observed the world and natural phenomena, and provided explanations to the deepest questions of mankind. They constructed theories that shaped and structured the world they lived in.

Western tradition says that, possibly, the first physicist was Pythagoras who studied the mathematical relationship between the length of a string and the sound it produces once plucked. He developed the idea of a musical scale and harmony, given by the sounds produced by strings whose lengths are in the ratio of small integer numbers. Acoustics and music, thus, gave way to one of the greatest revolutions accomplished by man: the description of the world through the use of mathematics. It is interesting to recognize how the idea of harmony, underlying these relationships, returns repeatedly throughout the development of science, although continuously changing shape. Subsequently, Archimedes, in the third century BC, gave other extremely significant contributions to physics: as a great mathematician, he formulated the laws of lever and floating, he dealt with optics and statics.

The intuitions and studies that gave life to the beginnings of physical science among the Greeks (as an example we can also recall Euclid's optics and Hero of Alexandria's studies on light and air) however remained almost buried, or in any case with few significant developments, for many centuries. In fact, tracks of good science (in today's sense of the term) which had, in fact, already appeared in ancient Greece (we can still remind Eratosthenes who measured the Earth's radius and the work of Ptolemy concerning astronomy) remained somewhat isolated, no longer taken up by the Latin culture, and then substantially lost and forgotten in the Middle Ages – apart from some great and important improvements produced by the Arab culture that has not only handed down the ancient knowledge, but produced important new ones as well –.

Modern science was born (or rather reborn, also thanks to the Arab culture and the rediscovery of classical manuscripts) just over four or five centuries ago, a very short time in the history of culture. With a great jump, later, mainly with Newton, the new science became a true theory, a true image of the world; a new world, with a new concept of true and false, of beautiful and ugly. The reconstruction here made of the beginning of modern physics is undoubtedly a bit emphatic and hasty [6]. But the point we wanted to put in evidence was that, gradually, physics has brought us into a new universe, more abstract and very different from the one imagined by our first ancestors which, in part, still shapes our naïve image of reality. Which of the two worlds is more real or truer, which more abstract or even invented? [7].

Often it is thought that the two worlds coincide, that they are the same world looked at and thought of, with more or less refined instruments. We do not believe this way. The world of physics is different than the common sense one, and not only because it recognizes more details, but because it establishes relationships between specially constructed concepts and concrete facts that do not belong to the common world. A physicist is not like an archaeologist who discovers an amphora in the sand [3], and since he has found it, he shows it in plain sight, so that it can be observed by all: that amphora was already there before, it was only hidden. Newton's laws of motion are not written in the experiments. In the usual school presentation of Newtonian mechanics, the term "force" is often associated with a reality in itself, as if the forces were independent and external elements of reality, real "things", existing entities. On the contrary, in the vision of the physical culture at the basis of the work presented here, forces assume their physical meaning only within the Newtonian theory, by means of the constraints represented by the three principles of mechanics. In other terms, the word "force" is in many respects similar to one of the primitive concepts of geometry, such as those of a point or of a straight line, which cannot be well defined and which are not even concrete objects of the sensible world, yet acquire their meaning – that is, they become elements of reality – within a specific theory by means of the laws or axioms that link their behaviour to that of other previously defined entities or to that of other primitive concepts.

Similar considerations become even more evident when we refer to Maxwell's electromagnetism. The electric and the magnetic fields are those "objects" of the theory that obey Maxwell's equations. Rather than describing electric and magnetic fields, Maxwell's equations implicitly define what they are. The great successes achieved by physical theories are due to the new ability/need to explain what is obvious, and can be "seen", by means of what cannot be seen and is unfamiliar to us. The history of ideas and the difficulties for the emergence of a modern scientific thinking, in fact, teach us that

> 'the real' is not what allows to be absorbed by a logical discourse but what resists it [8].

4. Methodological landscape

Professional physicists, as well as teachers, are so immersed in the reality of the physics world, in which they literally live, that they often think that it is enough to look, perhaps with a little help, at the things around us for everyone to see what that they see. Students' difficulties in studying physics show that, unfortunately, this is not the case. They need to learn to look in depth with new eyes and with new tools [9].

The new tools are purpose-built experimental apparatuses and specific conceptual structures. The language of physics is a mathematical, abstract, sophisticated one. His aesthetic canons are not those of natural wonder nor even those, albeit abstract, but certainly more common, of a painting or of a beautiful poem. It takes patience and passion for people, students for example, to get new tools and new eyes for a different gaze. In fact, it is natural that an untrained eye cannot see what… is invisible! We can only perceive what mental categories allow us to think. Once new categories have been constructed, new things can be thought, and, therefore, also seen. The effort to understand new physical concepts and ideas, therefore, inevitably passes through the acquisition of adequate mental categories.

Not only is the knowledge gained through physics and science important to society; so are also the awareness and the limits of the possibilities provided by their method of investigation which make this knowledge a "true" culture, a universal and typically human culture. And, therefore, the knowledge of how we do know is a fundamental pivot that revolutionizes conscience and that should be part of the heritage of mankind. This is why it would be extraordinarily important if science were considered really culture by everyone.

For this to be accomplished, theatre can help us. In fact, art in general, and theatrical art in particular, combine with effectiveness the possibility of using a known language with the ability to make us glimpse different worlds and with the possibility of looking at what we already know with new eyes. This is why science theatre is increasingly seen within the physics education research community as an effective tool to improve physics education [10]; and this is the reason why, since 2004, M. Carpineti, N. Ludwig and Author 1 have been promoting science communication through theatre [10-12].

Since 2004, the group "Lo Spettacolo della Fisica" (The Show of Physics) of the University of Milan has written and performed eight physics plays, making more than 400 performances and reaching approximately 130,000 spectators. Furthermore, it has also produced three lecture-shows: on the physics of food, on physics and art, and on quantum mechanics. The strategy adopted by the group was to write and stage real theatrical performances, often, but not always, with scientific experiments harmoniously inserted within the dramaturgy and proposing reflections on the meaning and role of physics, and often also providing strategies and methods to help teachers bridge the gap between informal, non-formal and formal education. The obtained results show that the dramatization of scientific learning through various means that encourage social interaction and reflection on historical topics is effective in engaging and motivating students and in helping them to grasp scientific ideas and concepts; moreover, dramatization also helps teachers understand what students are thinking [13].

In the last ten years, the collaboration between the "Spettacolo della Fisica" and the theatre company "Compagnia del Sole" – Bari (Italy), already started in 2008, has become increasingly solid and has also given rise to three shows, performed by Author 2, that have had the scientific advice of Author 1: "Il volo di Leonardo" (The flight of Leonardo), written by Author 2; "L'universo è un materasso" (The universe is a mattress), written by F. Niccolini and "Il messaggero delle stelle" (The messenger of the stars) written by the same author.

Furthermore, in times of pandemic, with the consequent suspension of theatrical activities, even the communication of science through theatre had to take different paths, and new strategies of contamination between theatre and science have been tested. One of these was "A scuola di volo" (At flight school) organized by the "Compagnia del Sole" and consisting of four remote and videoconference activities in the late afternoon lasting about two hours each, having philosophical-scientific themes, and in which – like in a literary lounge – myths, philosophy, science and art were discussed by Author 2, university professors (among them Author 1), other professional actors, and participants.

A reflection on the opportunities offered by this proposal led to the elaboration of a didactic proposal of a scientific online laboratory inspired by the "literary-scientific lounge" methodology offered by "A scuola di volo".

5. The "Principles and Equations of Physics" laboratory

By now, we know that the traditional structuring of physical knowledge, as presented by textbooks [14-19], does not provide the most effective framework for learning. With the aim of favouring a deeper understanding, it is necessary to carry out a revision of the organization of the teaching proposals for physics teaching, in a way that highlights the modelling character of knowledge, clearly showing the specific ways of physics of looking at the world and systematically comparing the complexity of concepts with the complexity of real facts [20].

5.1. Our research questions

With the aim of finding effective tools and methods to present physics in a way that makes people perceive its cultural aspect, we started research on the effectiveness of using multiple languages to address specific physics topics. The idea of the laboratory titled "Principles and Equations of Physics" was born, and soon included among the activities of the Italian Ministry plan PLS – "Piano Lauree Scientifiche" (Scientific Degree Plan), that had been structuring strong links between school and university since 2004.

Therefore, the following research questions were formulated:

RQ1. Can an approach that exploits and merges readings, drawings, applets, music, etc., foster perception of cultural aspects of physics?

RQ2. Does a multicultural presentation help understand specific physical topics?

RQ3. Is the simultaneous presence of students and teachers useful for training teachers?

5.2. The laboratory

In the A.Y. 2020-2021, taking also into account the problems arisen by the pandemic [21], the interdisciplinary and transversal multidisciplinary laboratory on fundamental principles and equations of physics was dispensed in participated online meetings. The central pivot of the laboratory was precisely physics, but it has been inserted in a broader cultural context concerning history, literature, philosophy, and, sometimes, even music, with possibilities for students to make connections and allowing metaphors between different physical aspects and different disciplines [22].

In Italian school, much emphasis is given to transversal, multidisciplinary and citizenship skills, but few are the teachers that actually try to really develop such skills in classroom. Very often the above-mentioned skills are confused with basic notions of statistics and probability, and a discussion about a sustainable use of energy (sometimes with standard evaluation forms prepared by publishing houses); teachers are therefore more focalized on giving notions than on reconsidering the very structure of new disciplinary Teaching-Learning sequences.

It is our belief that the multidisciplinary aspect of a discipline must be contextually inserted into the conceptual framework of the discipline itself. The inclusion of poems, anecdotes, readings and historical and philosophical considerations are not a purely decorative element, but help to clarify and discuss the physical aspects of the discipline.

Also to this purpose, the "Principles and Equations of Physics" laboratory has been performed at two voices, for integrating different skills and disciplines with the focus on physics.

The laboratory was intended for students and teachers, both as a basic workshop and as an activity in the context of what in Italy are called (PCTO) Percorsi e Competenze Trasversali e Orientamento (Transversal Paths and Skills, and Orientation). To this end, the interested students had to make a short video (of 5-10 minutes each) in which they proposed a personal remastering of the meaning of an equation or of a physics principle of their choice. In this, they were assisted by an expert who provided them with some basic video-making suggestions and tools. Since the videos produced all contained recordings or images of the students (for which we did not ask authorization for publication – we recall, in fact, that students were almost all minors, that the number of participants was decidedly high, and that we were also remotely, as we were in a pandemic), it is not possible for us to share such materials.

The contents of the meetings were essentially the three principles of dynamics and the law of universal gravitation, but the starting point was an analysis of what an equation represents in physics. Eight online meetings were held, seven of which of a disciplinary nature, and one (as already said) on the technical foundations for preparing a video. The project was born and developed in collaboration between the actor, author and theatre director Author 2, and Author 1.

The preparation of each activity, lasting an hour and a half, required an average of 30 hours of work. During the lessons, Author 1 had the task of presenting the physics topics with equations, exercises, simulations, epistemological considerations, and readings of scientific texts, while Author 2 had the task of carrying out readings and interpretations of artistic and philosophical texts or the presentation of paintings (*e.g.*, by Leonardo). Probably the most successful characteristic of the laboratory concerned the interaction between the two lecturers, while discussing some of the less evident aspects of what was being presented. In fact, Author 2 intervened with questions and provided suggestions – which produced dialogues with Author 1, and which were easily extended to the public – that greatly helped the structuring of a disciplinary-technical thought.

Given the success of the initiative, which involved approximately 120 students, the laboratory has been proposed again in the subsequent A.Y. (2021-2022), but with a new content: Maxwell's equations. This time we had to face a large increase in response with the involvement of about 650 high school students and teachers. Author 3 was responsible for the organizational aspect and analysis and evaluations of students' own videos of both editions. Moreover, Author 1, Author 2, and Author 3 made some individual interviews at the end of each course (with students and teachers), to discuss the strengths and the weaknesses of the activities.

As far as PCTO activities are concerned, we had also a collaboration with the laboratory on electromagnetism organized, again within the PLS, by Professor C. Fazio at the University of Palermo and which provided an experimental basis for the topics discussed.

6. Results and comments

In both editions of "Principles and Equations of Physics", teachers and students attended the laboratory together. This choice is part of the teacher training methodologies that comes from the research group on physics education at the University of Milan and which is centred on discussing and sharing proposals of teaching paths, working together with teachers and students.

We observe that the presence of students is particularly useful for teachers' training; in fact this allows them to immediately begin to observe the strengths and weaknesses of a given educational path right in the field; when a proposal directly centred on student involvement is provided, teachers are somewhat freed from fears related to non-comprehension; indeed, we observe that their questions were often worded "as if" they were asked by student, that is pretending to put themselves in the shoes of a student.

In the two workshops, the topics were proposed in a pedagogical way. The multidisciplinary context has served both to settle the principles of dynamics and Maxwell's equations in a cultural framework that is important and significant for today's students, and to provide some useful tools for the disciplinary appropriation of physics contents by students and teachers; moreover, it gave teachers an example of a Pedagogical Content Knowledge based proposal.

As regards the first edition (concerning the principle of Newtonian dynamics and the law of universal gravitation), it is interesting to note that only 7 of the videos sent by PCTO students (about 40) were designed according to methods resembling standard presentations of school textbooks; on the contrary, most of them presented the physics contents by linking specific disciplinary aspects with personal considerations (22 videos) or with the reading of poems not presented in the course (11) or with the composition and performance of music specifically created by a student studying composition; or also, as regards the first principle of dynamics, with videos of moving objects taken from inside a moving bus (3) or a camper (1).

The fact that students spontaneously decided to include music, poems..., in their videos, or choose to record videos from inside a moving vehicle, highlights how they perceived the need and the importance of a vision of physics "inclusive", even within their daily life experience. In this sense, it seems that an approach that exploits and merges readings, drawings, applets, music, etc., bears results to generate the use of physics as a tool for interpreting the world (RQ1). Furthermore, from a disciplinary point of view, the topics covered in the videos created by students were always completely consistent with the contents presented during the meetings: in particular, the majority of students opted for the first principle of dynamics (14 students) or for the law of universal gravitation (11); 7 participants chose the second principle, only 1 the third principle, and 6 chose, instead, to address all three principles together.

Concerning the second edition, that is the laboratory on Maxwell's equations, we give just few examples of the style of what was done. With the aim of helping the contextualization of what was discussed, images were shown of the places where James Clerk Maxwell lived (for example, his Glanlair estate and his home office) or of the drawings of James as a child (made by his cousin). Time was also dedicated to poems written by Maxwell, some joking, others really profound and linked to the history of his country; always with the goal to enrich the presentation by believing that aspects that are not strictly physical may contribute to the more strictly physical understanding of the proposed contents.

The evaluation of the initiative shows, in our opinion, two promising signals:

1) The first is the high appreciation of the course for what concerns its methods. In fact, the number of students and teachers following the activity did not substantially decrease over time. On the contrary, the number of participants has greatly increased from the first to the second edition of the laboratory. Moreover, in the individual interviews made at the end of the course (10 altogether between students and teachers), all the interviewees said they were interested in the methods of the laboratory. The teachers unanimously requested other laboratories to be carried out in the same way and concerning other aspects of physics.

   We also received many thank-you emails from teachers; as an example, we report an excerpt from one of them.

   > I can't help but write to tell you that your lessons are truly spectacular. In reality, it is difficult to find a suitable adjective to describe them because, in addition to having an excellent preparation, you have an uncommon ability to disseminate. I have a degree in physics, and I have always looked for a wider scope than the presentation of the mere topics: that attraction for art, music, philosophy, poetry which, in the eyes of others, seems to be contradictory for those who should only deal with laws and formulas, [...] has been amply repaid by your way of explaining topics, even the most complicated ones.

   Several positive comments were also expressed by many participants (both students and teachers). Here some examples:

   > Reconstructing the theory step by step, in an inductive way, is an aspect that I found particularly new and interesting.

   > I had never understood Plato as well as by following this course.

> Seeing that an important and famous scientist like Maxwell was also dedicated to writing poetry made me reflect on the fact that there is no separation between scientific and philosophical aspects.
>
> Lessons of this type could be presented in classroom, in every kind of school, as education for citizenship, and I hope that another course will be activated next year.

What has been written so far clearly indicates the quality of the proposal and its effectiveness for teachers' training (RQ3).

2) The second signal is the effectiveness of introducing in-depth discussion of physical aspects into proposed problems on electromagnetic induction. Faradays flux law and electromagnetic induction have generated the most interest [23,24]. In fact, while we had scheduled one meeting for each of Maxwell's equations, we had the urgent request to dedicate two meetings to electromagnetic induction; and so we did. The inclusion of this topic in a broad cultural context, the use of computer simulations taken from the Falstad website [25] and concerning the 2D and 3D simulations of electromagnetic fields have been very useful for discussing some of the more strictly technical aspects.
Great help was also given by slow-motion videos taken by our research group with experiments on induced currents, and by using a kit prepared by us in the European project TEMI – Teaching Enquiry with Mysteries Incorporated [26].
Moreover, the proposal of qualitative problems in which to discuss the presence or absence of an induced electromagnetic force – seen as composed of two terms: a motional term and a transformer one [27] – has, in our opinion, significantly increased a more active participation and the interest in this topic compared to other initiatives in which we had proposed it within a course structured in a more traditional way. Students and teachers gave us a lot of satisfaction; they worked very hard and with passion in the interpretation and explanations of qualitative problems related to the very difficult questions of transformal and motional electromotive force [28]. The formalization used was the "integral" one that is generally presented in Italian high schools, based on the concepts of flux and circulation, but making also some excursus towards differential operators and their meaning.
Furthermore, teachers told us that the students who joined the laboratory generally obtained considerably better results (compared to their classmates) in the ordinary assessment tests administered at school, on the topics in question. In this regard, we observe that the overall duration of the laboratory was 7.5 hours, a relatively short time. So, regarding RQ2, it would indeed appear that this cultural approach also serves to increase understanding of physics content.

7. Conclusions

The success of the two initiatives led the authors to adopt the same approach also in further activities, and has transformed many of their university's institutional teaching lessons.

Author 1 decided to structure his 27-hour module about Relativity (within the "General Physics 3" course for the third year of the degree in mathematics) using also philosophical readings, excerpts from scientific articles and poetry.

The approach was also followed by both Author 1 and Author 2 to prepare and implement, with the help of Author 3, the 2 credits course "Principia: from Quantum Mechanics to Field Theory", held online in Autumn 2022 for the II level master's degree in "Innovazione DIdattica in Fisica e Orientamento" - IDIFO21 (Teaching Innovation in Physics and Orientation) of the University of Udine. In this course, particular care has been given to the logical reconstruction of the process that, starting from a few important experimental phenomena, leads us to the construction of the principles and axioms and constitutive equations of Quantum Mechanics in a multidisciplinary learning environment.

Moreover, the activities described in this paper provide the basis and give the criteria upon which the PhD course of the University of Milan entitled "Instruments and methods for a cultural understanding of physics" by Author 1 and Professor N. Ludwig has been designed; the course started in mid-December 2022.

In the near future, the videos (unfortunately only in Italian) of the meetings on Maxwell's equations will be made available on the PLS physics website of the University of Milan [29].

Finally, regarding the two laboratories discussed in this paper, a new edition of both is planned for the A.Y. 2023-2024. Both paths will be implemented through new questions created with *Kahoot!* to be asked during the meetings, and the preparation of Google Forms, with exercises for the participants, to be administered at the end of each meeting. In this way it will be possible to obtain further data of the learning results on some specific issues, such as those concerning electromagnetic induction.

References

[1] Giliberti M 2014 Theories as crucial aspects in quantum physics education *Frontiers of Fundamental Physics and Physics Education Research* ed B G Sidharth, M Michelini and L Santi (New York: Springer) pp 497-503
[2] Cavallini G and Giliberti M 2008 La lezione dalla Fisica Quantistica *Epistemologia* **31 (2)** 219-240
[3] Giliberti M 2017 L'aspetto fondamentale della teoria nella didattica della fisica quantistica *Giornale Italiano della Ricerca Educativa – Italian Journal of Educational Research* (Lecce: Pensa MultiMedia Editore) pp 29-40
[4] Kragh H 2002 *Quantum Generation* (Princeton: Princeton University Press) p 397
[5] Lorenz K 1974 *L'altra faccia dello specchio* (Milan: Adelphi) p 27
[6] Renn J 2012 *Sulle spalle di giganti e nani – La rivoluzione incompiuta di Albert Einstein* (Torino: Bollati Boringhieri) pp 146-148
[7] Giliberti M 2014 Fisica a teatro (Ariccia: Aracne) Chapter 3
[8] Morin E 2008 *La Methode – Tome 1 – La nature de la nature* (Paris: Edition du Seuil) [cit. in Sofia G 2011 Ritmo e intenzione scenica. Ipotesi su teatro e neurofenomenologia *Nuovi Dialoghi tra teatro e neuroscienze* ed C Falletti and G Sofia (Spoleto: Editoria e Spettacolo) p 160].
[9] Bertolini M, Dedò M, Di Sieno S and Turrini C (Eds) 2005 *Con altri occhi – sguardi matematici e non sulla città* (Milan: Electa)
[10] Ødegaard M 2003 Dramatic science. A critical review of drama in science education *Study in Science Education* **39 (1)** 75-101
[11] Carpineti M, Cavinato M, Giliberti M, Ludwig N and Perini L 2011 Theatre to motivate the study of physics *JCOM* **10 (1)** 1-10
[12] Giliberti M 2021 Stories and Theatre for Teaching Physics at Primary School *Educ. Sci.* **11 (11)** 696
[13] McGregor D 2014 Chronicling innovative learning in primary classrooms: Conceptualizing theatrical pedagogies to successfully engage young children learning science *Pedagogies: an International Journal* **9 (3)** 216-232
[14] Amaldi U 2020 *Il nuovo Amaldi per i licei scientifici blu* (Bologna: Zanichelli)
[15] Caforio A and Ferilli A 2020 *Le risposte della fisica* (Florence: Le Monnier)
[16] Cutnell J D, Johnson K W and Young D 2018 *Physics. 11th ed.* (Hoboken NJ: Wiley)
[17] Halliday D and Resnick R 2018 *Fundamentals of Physics. Extended. 11th ed.* (Hoboken NJ: Wiley)
[18] Serway R A and Jewett J W 2013 *Physics. 9th Edition* (Boston: Brooks/Cole Publishing Company)
[19] Walker J S 2017 *Physics 5th ed.* (Bellingham WA: Western Washington University)
[20] See, for instance the whole volume: VV. AA. 1995 *Thinking Physics for Teaching* C Bernardini, C Tarsitani and M Vicentini (New York: Plenum Press)
[21] Marzoli I, Colantonio A, Fazio C, Giliberti M, Scotti di Uccio U and Testa I 2021 Effects of emergency remote instruction during the COVID-19 pandemic on university physics students in Italy *Phys. Rev. Phys. Ed. Res.* **17** 1-18
[22] Fazio C, Carpineti M, Faletič S, Giliberti M, Jones G, Mcloughlin E, Planinšič G and Battaglia O R 2021 Strategies for Active Learning to Improve Student Learning and Attitudes Towards Physics *Teaching-Learning Contemporary Physics: From Research to Practice* ed B Jarosievitz and C Sükösd (Cham: Springer) pp 213-233

[23] Maloney D P, O'Kuma T L, Hieggelke C J and Van Heuvelen A 2001 Surveying students' conceptual knowledge of electricity and magnetism *Am. J. Phys.* **69** S12
[24] Zuza K, Guisasola J, Michelini M and Santi L 2012 Rethinking Faraday's law for teaching motional electromotive force *Eur. J. Phys*. **33** 397-406
[25] https://www.falstad.com/mathphysics.html last access 03.12.2022
[26] TEMI. European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 321403 - 2012-1. http://www.projecttemi.eu/
[27] Cavinato M, Giliberti E and Giliberti M 2022 Conceptualization of electromagnetic induction at various educational levels: a case study *Canadian Journal of Physics* **100 (5)** 1-14
[28] Giliberti M and Cavinato M 2022 Percorsi didattici come strumento di formazione insegnanti. Un esempio inquiry based: Induzione Elettromagnetica – Didactic paths as a teacher training tool. An inquiry-based example: Electromagnetic Induction *Giornale di Fisica* **63 (s2)** 21-40
[29] https://pls.fisica.unimi.it/