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Experimentation and Research in the Physics Course for the Preparation of Primary School Teachers in Naples

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Abstract: Physics preparation for primary school teachers has received attention only in recent decades. Research on science education provides useful guidelines, often disregarded. Several interrelated research questions must be addressed by field research, namely, (a) which physics subjects to teach in primary school and its relationships with other sciences, technology, and mathematics; (b) how to prepare teachers to grasp the complexity of their tasks; and (c) how to bridge pre-service and in-service training. In this study, we describe innovative aspects of a course, based on the research and action research of our research group, that aims to overcome the limitations of a purely academic approach. Future teachers are dynamically involved in activities in informal and formal contexts and in the training of in-service teachers' activities. The idea of cognitive resonance and a phenomenological approach to the modeling process are the basis of the activities that integrate key concepts of physics with transversal ones to develop skills in physics, mathematics, technology, and language. Field research carried out with qualitative methods shows that the course, despite being demanding, is well received by students. Dozens of students are then involved in the activities of the group when they start a teaching career at school.

Keywords: prospective primary teachers; modeling and phenomenological approach; cognitive resonance; formal and informal contexts

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1. Introduction

Science education in kindergarten and primary school is a focus of attention of educational systems around the world. Research-based guidelines and indications on scientific teaching emphasize the need for curricula that span longitudinally throughout the school years, achieving unity and continuity in the presentation of scientific disciplines. In our opinion, the most advanced proposals are those highlighting the need to develop articulated skills, through the role that scientific education can play in the development of critical thinking and in the cultural education of citizens [1]. This attention is particularly important in kindergarten and primary school: "children's work can be integrated with other subject areas, such as language, arts, mathematics, and computational thinking. Integration, if done well, contributes to building meaningful bridges across content areas" [2]. Children's learning is a social and cultural process. Children develop science skills in childhood through family relationships and playing. Adults, family members, and teachers play crucial roles in supporting children's learning in science, both in making sense of their experiences and supporting reasoning about the interpretation of natural phenomena [2]. Research has shown that a combination of educational strategies in classroom management and a well-structured curriculum (with the indication of previously tested teaching materials and resources) can have a significant impact on the performance of students in school [3]. This suggests that proper science teacher preparation must be able to integrate social, pedagogical, and disciplinary aspects.

In recent decades, research in physics education has produced significant contributions to science and mathematics education for all school levels. The most interesting research results were collected from the education systems of different countries. These provide indications, guidelines, and standards to improve physics teaching at school by non-traditional activities and offer suggestions about teacher preparation. However, the impact on teaching is still insufficient, and how to fill the void between research and practice is a matter to be considered. It is a complex topic and it seems the problem cannot be solved without a global approach requiring wide-range interventions of a cultural nature, e.g., a radical revision of the role of school. It is widely accepted that scarce reference to research findings and national indications is mainly due to the inadequate preparation of teachers. This is particularly true for preschool and primary school, where teachers usually prefer topics such as biology and geography and avoid chemistry and physics. In general, national guidelines give freedom in the choice of subjects and teachers often choose those in which they feel most confident. It is therefore arguable that kindergarten and primary school teachers need specific support for physics and physics education [2]. In Italy, the problem is made even more evident by the scarce diffusion of physics laboratory activities in high schools.

The Pedagogical Content Knowledge (PCK) framework, introduced by Shulman [4], revisited and made much more dynamic than the first schematic version, is evident in research work in physics education, and its examples seem to be of great use for teachers. The Conceptual Change perspective also seems to offer many interesting insights on how to prepare for teaching physics. Both these frameworks and the work that refers to them offer ideas for the initial and in-service preparation of teachers. However, in our opinion, most of the work gives excessive emphasis to the static and decontextualized role played by the so-called misconceptions (even classified as typical errors, alternative ideas, etc.), and in some cases, reduced it to a catalogue of misconceptions that now concern all areas of physics (and for some mathematics) at different levels of teaching, with the risk of providing alibis and even de-responsibility to teachers in their educational function. Sometimes, the contribution that physics education research provides in the training of future teachers is limited to the subject matter in light of known learning difficulties and how to detect them through standardized tests and questionnaires [5]. Furthermore, the examples of intervention in the classroom that are presented as good practices to overcome the difficulties often appear to be self-referential and difficult to put into play, as suggested by their low impact on teaching practice. The integration of pedagogical aspects in physics teaching cannot be limited to the knowledge/interaction between the accredited model of a phenomenon and a list of spontaneous ideas, as some hasty recipes seem to suggest. Indeed, it seems more interesting to use these frameworks in a dynamic way [6] during teacher training, so that each teacher can broaden his/her PCK in relation to the particular context in which he/she will be called to model a physical phenomenon, by prefiguring how he/she will interact with children in a real classroom. Hence, there is a need, from our point of view, to rethink the concepts and structure of physical theories in a didactic perspective, making the modeling process central. In this field, physics and physics education have a lot to teach. The point of view of physics in investigating and modeling phenomena by proposing continuous and bidirectional relationships between evidence, conjectures, models, and theories is perhaps the most significant contribution that the teaching of physics can offer to the teaching of other scientific disciplines and mathematics [5].

2. The Course

In teacher training courses, activities are usually divided into lectures, workshops, and teaching practice at school, with different proportions according to the country. Teaching activities, often resulting from partnerships between school and university, seem to have a significant impact on future teachers [2]. In the meta-analysis by Dunst et al. [7], it is shown that the most fruitful activities are a prolonged teaching period (at least ten weeks), coaching, and peer interaction. Our experience agrees with these results: teacher training works better if it is also framed in action research activities that are grounded in the social context of schools, involving different actors that participate in science education in both formal and informal contexts [8–10].

Many studies on kindergarten and primary school teacher training focus on teachers' expectations and perceptions of a professional future. Russell and Martin [11] argue that learning experiences previously experienced by future teachers are of particular importance. Special emphasis should be given to autonomy, responsibility, critical thinking, and self-reflection on their basic knowledge [12,13] and on their future teaching method [14]. To succeed in this goal, they should actively participate in the learning process and address scientific content through a continuous process of metacognition. Two factors play primary roles in promoting teaching, namely, the development of professional learning [15] and the cooperation between researchers and teachers in research programs. Future teachers should develop an idea of their future work during their studies by participating in action research activities [16]. Many primary school teachers choose not to deepen scientific topics or to exclude them from the curriculum because they do not have a solid knowledge of the subject, which also leads to low self-esteem. As a result, if not completely avoided, scientific subjects are treated only through textbooks and prescriptive worksheets, completely excluding experimental practice and critical discussion [17,18]. The solution to this problem is not to expand preparation programs with more scientific content [19]. Future teachers should realize that scientific knowledge is not a collection of facts, formulas, and problems, and that learning does not consist of memorizing concepts, a common view among university students [20]. The risk is that this approach to science will then be carried over into teaching practice. It is imperative for teachers to have the opportunity in their initial training to analyze and reflect on the ways in which they are prepared, as they will reasonably feel more comfortable with what they have experienced as students.

From the picture just outlined, it emerges that the problem of the initial preparation of science teachers is particularly complex and that much research and experimentation must be carried out. However, it seems that research in science education is beginning to seriously deal with teacher training. A recent review provides a detailed picture of findings from field studies and of questions still to be investigated on the scientific training of preschool and elementary school teachers. The picture is also interesting for the connections it shows between initial and in-service training. The aspects taken into account to study their effectiveness in teachers' training are (a) the development of disciplinary knowledge, (b) the perceptions and adequacy in relation to scientific teaching, (c) the hands-on and laboratory practices, and (d) the ability to build teaching material [2]. These studies also made use of control groups and observation in teaching activities, drawing comparisons with traditional courses. They show that courses taking these aspects into account can overall improve the training of future teachers for both the disciplinary content and for their self-confidence [21–23]. For example, it emerges that a determining factor in achieving this goal is linked to the peers' confrontation about their future work [24]. Other works show that such innovative courses help develop the ability to make educational material for children [25].

In designing the course contents, we have kept in mind that physics, in primary school, is not a specific discipline, and that teachers usually feel more confident in life or earth sciences [26]. Teacher beliefs are emergent in practice and change over time and across contexts [27,28]. The basic knowledge of physics key concepts and methods is a prerequisite for dealing with scientific phenomena of daily interest. In particular, the typical method of physics to build models and theories is crucial for other scientific disciplines and for introducing and managing concepts and operations in mathematics [29]. Therefore, the course also aims to show the important role that physics can play in scientific education in general. On the other hand, results coming from physics education research are of great help in rearranging phenomena of interest for biology and geology in a conceptual and not purely informative key. More generally, the course aims to share with future teachers the building and use of resonant models for the interpretation and management of structures of reality, at different levels of phenomenological and cultural experience. To avoid schematism and pure cataloging of facts (even if falsely "discovered" in the laboratory), it is crucial to work on the modeling process and on the many interrelated ways in which a model can be represented. In the modeling process and in the progressive construction of knowledge, we work to realize that for the model to be "appropriate" at an individual level, didactic mediation is required. This mediation takes into account basic cognitive strategies, privileging potentialities, and resources that are always present in order to improve and reorganize networks of concepts that are gradually more articulated. Therefore, without ignoring the way in which the construction and interpretation of models framed as coherent theories are developed, in the course, we ask students to share with us their continuous rethinking about their own teaching perspective. In this way, we try to critically engage teachers with metacognitive strategies aiming to tie the things they learn with the way they will teach them.

A phenomenological approach [5,30,31] to the modeling process is the cornerstone of our course. The cognitive–pedagogical model of reference results from the work our group has carried out over the years to establish a general framework for the revision of disciplinary contents in didactic key. Learning how to teach involves a process of resonance between individual cognition and social culture. A drawing of cognitive resonance model of Paolo Guidoni is shown in Figure 1.

Figure 1. Paolo Guidoni in an activity on phenomenological approach and modeling in a primary school. On the right, one of his drawings about the multiple connections between experience, language, and knowledge, aimed at explaining his model of cognitive resonance. Copyright 2018 Copyright www.les.unina.it.

The model is centered on the metaphorical notion of cognitive resonance (and the associated metaphorical notions of clustering such as correlation, interference, coupling, redundancy, variation, and so on): a notion that is seen, with all its implications, as a powerful key to make visible, evoke, and put into operation some basic dynamic characteristics of human cognition that play crucial roles in understanding physics.

In the training model we propose, this involves the design of resonant teaching strategies to be adapted to the needs of students and to consider their perceptions and their experiences. The disciplinary contents we propose are revisited and reoriented for didactic purposes to be as resonant as possible with the basic knowledge of future teachers. In this way, we try to generate in the students a perception of the relevance of the training they are undergoing. The contents of the course are developed along two intertwined lines as shown in Figure 2: on one hand, activities addressing (from both an experimental and formal point of view) core ideas of physics and transversal concepts that constitute the common ground of various scientific disciplines; on the other hand, activities aimed at reflecting more generally on children's cognitive development and how we can support it by working at the same time with physics and language, physics and mathematics, physics and technology, and physics and art.

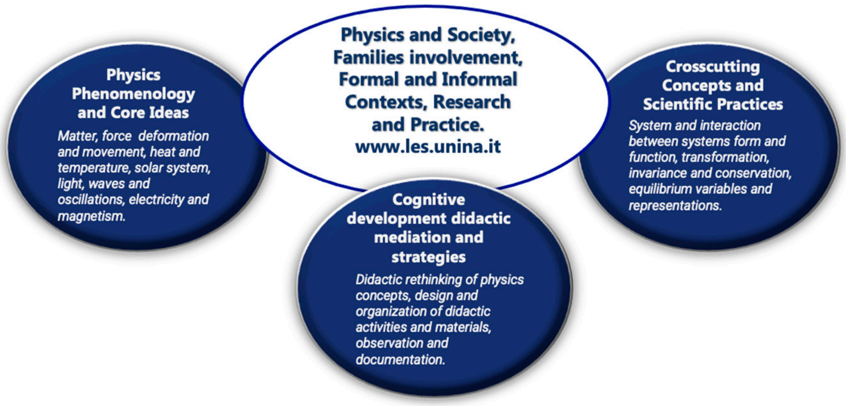

Figure 2. The organization of the course contents and the relationship with the activities of our research group, with a crucial role played by the LES website.

As already described, one of the elements that characterizes the course is the interaction with the experimentations that our group carries out in formal and informal contexts. During classes, students are invited to reflect on the social dimension of science teaching and on the strategies we adopt in involving adults in our projects. Particular attention is given to learning in informal contexts [32] (e.g., science museums) and how these experiences can be worked into the classroom. This link is kept alive by the material published on the LES website, while a smaller group of students is actively involved on a voluntary basis in field activities. Our research group has been involved since 2018 in two projects to contrast educational poverty funded by the social enterprise ”Impresa Sociale Con I Bambini” (https://www.conibambini.org/en/who-we-are/, accessed on 12 January 2022). Both projects aim at strengthening the educating community by triggering virtuous paths, individual and collective, to prevent at-risk children from leaving school. Both projects offer a rich panel of educational activities involving schools, voluntary associations, and cultural institutions. The contribution of our group focuses on the role that scientific education can play in the cultural background of citizens, and this requires a non-traditional approach to teaching with all the subjects involved (http://www.les.unina.it/?p=2080, accessed on 12 January 2022). We organize laboratory activities in schools and territorial centers, workshops for parents, and training courses for teachers. At present (March 2022), hundreds of children and adults have been involved in our activities. Teaching and documentation materials are available on the LES website (http://www.les.unina.it/, accessed on 12 January 2022), and the whole experience involves students of primary education, often in the context of experimental theses.

Following the COVID-19 emergency and lockdown, we have made efforts to give continuity to all ongoing activities using well-known online platforms and the LES website. Teachers, children, and parents acting as “home teachers” documented their experiences with videos (https://www.youtube.com/watch?v=o8Hov1WxIi0, accessed on 12 January 2022).

2.1. Examples of Didactic Activities with Children and Future Teachers

In the following, we present two examples of didactic activities that our group developed. Previous studies that refer to proposals and educational materials are available in ”Risorse didattiche, libri e quaderni di lavoro”. These were documented in some detail and later used in the training courses for future teachers. The didactic material collected is also a guide for the experimental activities of the degree theses. There is no rigid sequence in the development of the activities, since we try to adapt to the specific context at hand. However, the structure we generally adopt is the following:

1. We present the experiences we carry out in some schools with videos, drawings, and sentences of children who interpret the observed phenomena;

2. We reproduce experiences in the classroom that directly involve students, both in the modeling of the phenomena under study and in the didactic management of activities at school;
3. We share reports and in-depth materials about the experiences we have had; and
4. We involve students in carrying out activities at home by sharing materials on the LES project website and in classes devoted to specific laboratory activities.

Here are some examples that illustrate our strategy. The first example is devoted to the phenomenological area of "light, color and vision", and the other covers the transversal area we call "machines and mechanisms".

2.1.1. Light, Color and Vision

This theme is one of the most engaging for students in both kindergarten and primary school. Two aspects are fundamental here: scientific concepts can be constructed starting from children's perceptions (vision); it is recognized that physics school teaching "in chapters" (geometric optics, electromagnetic waves) obscures the underlying unity of the subject and its interesting connections with chemistry, biology, physiology, neuroscience, and language. These connections make the study of light fascinating, intriguing, and potentially able to promote the development of complex skills that are the main goal of science education at school.

On this subject, research in physics education offers vast literature on the strategies to be adopted, offering examples of successfully tested educational paths, hands-on teaching resources, and applets for activities in formal and informal contexts (www.compadre.org/per/; www.exploratorium.edu/search/light; https://phet.colorado.edu/, accessed on 20 January 2022). Our research group has developed a large amount of material on the subject since the 1970s when workbooks (now available on the LES website) were developed by national coordinators on physics education for basic school. A specific laboratory is devoted to light, color, and vision in the primary education sciences course.

In Figure 3 are shown some examples of activities taken from the LES website that we have previously experienced in kindergarten and primary school. The didactic path on luminous phenomena is presented with a rich documentation and we revisit and share with future teachers the choice of materials used, the pedagogical model, and the children's answers.

Figure 3. Children of the first year of primary school "M. Assunta". Introduction of the activity with multiple reflections of the spots of sunlight entering the window and then exploration of the phenomenology of reflections with flat and folding mirrors. Copyright 2018 Copyright www.les.unina.it.

Children in kindergarten and primary school "play" with the phenomena related to the propagation of light and the formation of images. Children are guided in a process that gradually leads to the definition of entities that schematize and model objects and phenomena that are observed. We play with natural and artificial light, and with the help of shadows and wires stretched along their edges so the path of light is reconstructed. Beams of light are obtained from torches through diffusion by sheets of white paper, on which many rays of light are drawn; the ensemble of these rays may be representative of the entire beam (see Figures 4 and 5). In this way, we try to avoid incomprehensible textbook schemes that the literature on physics education indicates as generators of "misconceptions". Strong ideas from Hellenistic science are also discussed with students, arguing about the role that models and drawing have had in the development of Euclidean geometry. Euclid is known above all for "The Elements", but he is also the author of an optics treatise, and it seems that he had a clear idea about the relationship between physical objects and geometric (abstract) entities [33]. The idea of a ray that we use in the drawing (a segment) and therefore the relationship between the reality of a luminous brush and its representation is supported by the use of laser sources (even with parallel brushes), drawings, and simulations that allow a thorough investigation of models in geometric optics. The study of shadows in sunlight and with "point-like" light sources allows us to explore affine and projective transformations, an interesting area of geometry that is often overlooked (see Figure 6). As happens in activities with children, with future teachers' geometries are defined through the invariants that characterize them. Despite the apparently too formal approach, the search for invariants is connected to the transversal concept of conservation, and teaching to recognize what changes and what remains unchanged (or is preserved) turns out to be a strategy of great use, not only to shift attention from figures to transformations (it is necessary to consider associated pairs of obstacles and images), but also to stimulate observation by focusing on correlations. For adults, the topic is an opportunity to reflect on the concept of correspondence, function, and to introduce ideas related to algebra and group theory.

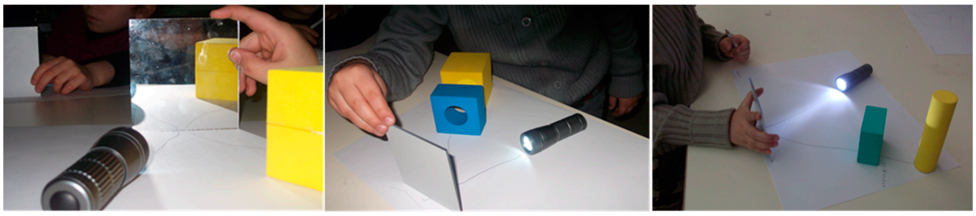

Figure 4. Reconstruction model of the path of light. The light emitted by the flashlight hits the flat mirror and must pass through a hole in one block to hit a second block. The diffused light on a sheet of paper on the table allows us to draw rays of light and, in particular, some representative rays. The letter V drawn by the children represents the path of the central part of the light beam (projection on the sheet of the axis of the cone).

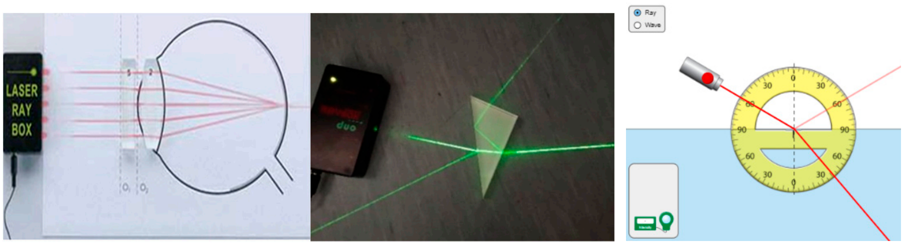

Figure 5. With fine brushes of laser light, we work on the concept of the light beam. With parallel brushes, we reconstruct the images with the ray method (on the left, a model for the correction of a vision defect), and with an applet, we work with Snell's law on reflection and refraction.

Figure 6. Both outdoors and indoors, the rectilinear propagation of light and the formation of shadows (with the sun or with a lamp) is an opportunity to deal with both students and future teachers the invariants of geometric transformations (affine geometry and projective geometry). Copyright 2018 Copyright www.les.unina.it.

2.1.2. Machines and Mechanisms

In our activities, we strongly emphasize the study of machines and devices, both analog and digital. In pure mathematics, for example, mechanical drawing machines are useful tools for the study of remarkable curves such as conic sections. In many cases, the design of the drawing machine mirrors the curves' defining properties, that are thus perceived in a dynamical way. A historical digression about this: as a matter of fact, Isaac Newton invented calculus (and dynamics) by a kinematical study of geometrical curves. In the 17th century, this approach was called *geometria organica*, where *organica* comes from Greek and means "mechanical". So, in some sense, the mechanical study of curves was a cornerstone for the development of modern calculus.

In physics, the analysis of the internal working of machines and measurement devices is a great opportunity to clarify important aspects of the scientific method, such as the relationship between theoretical entities and measurement processes. In the modeling process, familiarity with machines and mechanisms also has a great cognitive value, since the mechanical metaphor lies at the heart of every cause-and-effect reasoning and is of utmost importance in physics. Moreover, in modern physics, operational definitions that specify how a physical magnitude must be measured have been recognized as a powerful way to avoid inconsistencies and gain insight into fundamental concepts. In Figures 7 and 8 are shown some examples that illustrate our use of machines and mechanisms in our activities.

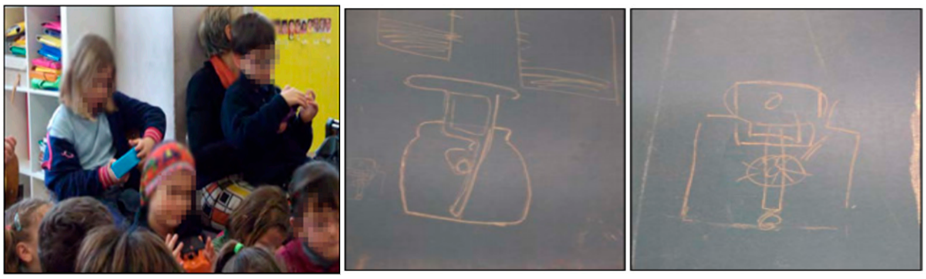

Figure 7. Second-year elementary school children "feel" the elastic force with their eyes closed. Then, they are asked to graphically represent the mechanism. On the right, some drawings on the blackboard. Only after a discussion involving the whole class do children observe the mechanism with a "transparent" scale. Copyright 2018 Copyright www.les.unina.it.

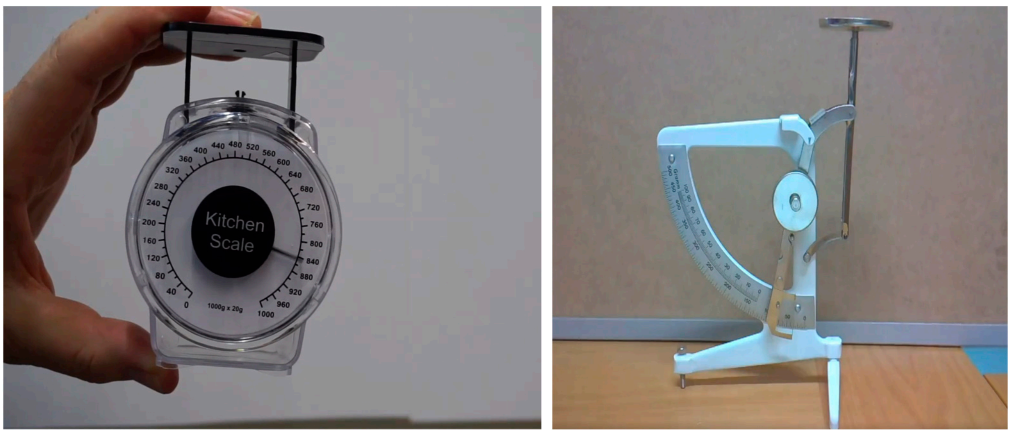

Figure 8. The activities carried out with the children at school are analyzed with students of the training course. The transduction mechanism is also analyzed in detail with an analysis of the characteristics of the measuring instrument (precision, sensitivity, range, etc.). The comparison with the letter balance (in which the articulated parallelogram is present) allows us to explain interesting problems about the equilibrium between different forces and moments of the forces.

The Spring Dynamometer

A central issue in mechanics is the unambiguous definition of force. Since the word *force* comes from everyday language, with both adults and children, we usually start this topic with an open discussion about the variety of contexts in which the word is used, both literally and metaphorically. To proceed, we build on the intuitive notion of force as muscular stress and analyze the possible effects that can be observed by exerting a contact force on a body at rest. These are essentially two: movement, if the body is approximately free, and deformation, if it is constrained. We focus on the latter, making a distinction between rigid, plastic, and elastic behavior. Forces are invisible, and with children, elastic materials work effectively as *dynamoscopes*, i.e., objects that exhibit the presence of a force by a change in their state. After a qualitative exploration of elastic properties of different objects, we introduce the problem of comparing forces with one another and the idea of *dynamometer*, i.e., a device that uses elastic behavior and a graduated scale to give a quantitative measure of an applied force. The operations involved in the building of such a device lead quite naturally to Hooke's law, the empirical relationship that expresses direct proportionality between applied force and deformation of a spring. We remark that in our treatment, Hooke's law is not given a priori but is the idealized synthesis of real measurements.

With adults, we dwell in a detailed discussion of the working principles of the spring dynamometer, touching many of the cross-cutting concepts that lie at the core of our course: systems and interaction among systems, equilibrium, measure, variables, and representations. There is a clear distinction here between the measuring system and the system that is measured, interacting with each other, and the measurement itself is based on an equilibrium between them. The calibration procedure highlights the fact that, ultimately, any measurement is a comparison between systems, with the measuring device working as a mediator for this comparison.

Speaking of measurement in general, the spring dynamometer is also a perfect example of transduction system, i.e., a system that operates a conversion from a magnitude to another through a controlled process. This kind of translation, as is well known, is unavoidable when we measure intensive magnitudes. In this regard, it is useful with both children and adults to draw a comparison between force measurement (by a dynamometer) and temperature measurement (by a thermometer): in both cases, all we can observe is the effect caused on a suitable device by a change in the magnitude to be measured. The elastic properties of a spring play the same role as the dilation properties of a thermometric liquid, and in both cases, the graduated scale depends on their arbitrary choice. Finally, both the spring dynamometer and a liquid thermometer can be used to give an operational definition of force and temperature, freeing ourselves from the ambiguity of ordinary language. Starting from the operational definition of force, it becomes easier to see why we may use the same word *force* to describe different phenomena such as gravity, magnetism, or contact interaction: they have the same effect on a conventionally chosen device that can be used to make a quantitative comparison between them. With a clear perception of this, all subsequent study of forces in static conditions can be carried out with the help of spring dynamometers in a meaningful way.

To make contact with everyday experience, throughout the discussion, we often refer to a kitchen scale, a good example of a spring dynamometer that is familiar to most students. It is interesting to look at the differences between the transduction processes operating in a standard spring dynamometer and in a kitchen scale. In the former, the force has to be a *pull* and the output magnitude to be read on the scale is a *length*; in the latter, you have to *push* and the applied force is converted to an *angle* on a quadrant. Inspection of the interior of a kitchen balance shows that in addition to the spring, the transduction process involves two more components: a toothed wheel and an articulated parallelogram. Together, they operate a geometrical transformation that converts the translation of the plate to the rotation of a pointer. We emphasize here the importance of direct proportionality, crucial to the proper working of most measuring devices: we want equal elongations of the spring to correspond to equal angles traced by the pointer, and this is possible only if the transformation from length to angle is linear. To extend the discussion to adults, it is also interesting to analyze the letter scale, a sensitive device whose working principle is equilibrium between force momenta. Finally, we discuss advantages and limits of these devices in terms of sensitivity, precision, and practical use.

The Motion Detector

In the study of motion and its representations, we make great use of MEMS-based motion detectors (MD) that measure distances by echolocation, a process also used by dolphins, bats, and visually impaired people as a substitute for vision. The magnitude directly measured in echolocation is the time interval Δt between emission and reception of very rapid sonic or ultrasonic impulses, from which, given the speed of the signal v, the distance of the reflecting obstacle d is calculated as $d = v\ \Delta t/2$. On the other hand, if the distance of the obstacle is measured in an independent way, inverting this formula, the MD can be used to estimate the speed of sound propagation.

MDs are extremely useful to explore kinematics. Moving objects in front of the MD results in real-time plots that can be analyzed to highlight the correspondences between real motion and its geometrical representations. An interesting activity for children is drawing an assigned 1D space-time plot with their own body, walking up and down in front of the MD. Through this experience, the kinematical meaning of geometrical features such as stationary points, slopes, and intercepts is clearly perceived. With adults, the real-time generation of plots is helpful to discuss the connections between kinematical quantities such as distance, velocity, and acceleration.

Turning to the measurement process carried out by the MD, from an operational standpoint, the distance measured by echolocation is something different from the distance measured by a ruler, and the problem of their consistence can be discussed. Moreover, echolocation is based on some assumptions about sound propagation: using the simple formula above for the distance of the obstacle is in fact equivalent to assume a corpuscular model where pulses move uniformly in a straight line. It is important to discuss the limits of this model and its connections with the wave model, an aspect touched upon also in our activities about light, colors, and vision.

An interesting feature of many MDs is that they are fully programmable by the user. Inspecting the code is like looking at the gearwork of a hidden mechanism, since its structure mirrors the operations carried out by the device and the theoretical model on which they rest. This code can be freely modified, and tinkering with it is an excellent way for both adults and children to integrate coding, mathematical reasoning, and physical modeling in a meaningful way.

It is generally accepted that the development of computational thinking must receive particular attention in the proposals on science education with a strong impact on transversal skills [34–37]. The didactic focus on computational thinking was emphasized by Seymour Papert in 1980 [38], and subsequently rethought in 2006 by Jeannette Wing [39], who elevated it to a fourth basic skill along with reading, writing, and calculating. Together with the use of new technologies, computational thinking can help students and teachers to experiment with new educational paths in which it is necessary to mobilize imagination, practice, and logical deductive thinking in a creative and original way. In our course, the need to develop computational thinking is addressed by critically analyzing experiments in which we involve children and teachers at school and in informal contexts. An example of our approach is Lucia Ranucci's recent thesis "Art, Science, Game. Making and Tinkering in Primary School" [40]. In the experimental part of this work, Ranucci developed a proposal on the integration of Scratch and MakeyMakey. The activities allowed children to work with codes in Scratch and to interact with the variables of the algorithm, using their own body to open and close a circuit with the MakeyMakey board. As well as in other experiments on the targeted use of new technologies that we have carried out in our thesis work, the favorable results obtained with children with learning difficulties are discussed.

2.2. In-Service Teacher Training Activities

Our research group has been involved for years both in the initial and in-service training of teachers, and a distinctive feature of our course is the attempt to link these two in a fruitful way. Classes are organized by integrating reflections on the contents and teaching methods with the description of the experiences that our group carries out with students and teachers at all school levels. For in-service training, our group has been involved over the years in the design and implementation of local, national, and international projects. These experiences have taught us that laboratory activities, albeit necessary, are not enough for effective training. In-service teachers must be involved in activities that allow them to reflect on their daily practice and on flexible innovation proposals that show the possibility of adaptations to different contexts. The experimental activity aims at modeling the physical phenomena explored and, at the same time, at reflecting on the way in which children can be involved in suitable analogous modeling processes. Therefore, the supporting materials we use include different didactic proposals, books, worksheets, videos, systems for real-time acquisition, and applets. With teachers, we share reflections about how to make the proposed activities stable and sustainable at school. For effective training, it is necessary to involve groups and not individual teachers in different schools. Cooperation with colleagues is invaluable for teachers' work because it promotes reflection on practice and, therefore, professional development of teachers themselves. Educational policies should recognize peer cooperation and sharing as a structural part of teachers' practice and provide adequate resources in terms of time, space, and training. The world of educational research should critically reflect on the opportunities to effectively promote cooperative practices and shared reflection in teachers' training and self-training.

3. The Field Research

In the first year of our course, field research was carried out to test its impact. The survey included questionnaires, in-depth interviews, and a focus group. The results that emerged from a qualitative cross-analysis of these data show that the course, although demanding, is well received [41–43]. In this section, we illustrate and discuss the data collected in the academic year 2020–2021.

The material was collected in a process which, although not in chronological order, is described in the following:

- Access to the educational resources of the LES site on experiments carried out by our research group in schools and documented with stories and comments on the activities carried out. These documents have been integrated with the material collected in the classroom by the students on the same topic and used as study material for the final exam, and guide results for the documentation of the experimental activities carried out in some thesis works.
- Activities with children in the context of projects against educational poverty.
- "Exercises" on areas of phenomenology with experiences at home and in virtual laboratories.
- Participation in field activities with children in formal and informal settings.
- Participation in in-service teacher training activities.
- Thesis work with experimental activities.
- Individual interviews.
- Participation in focus groups.

At the end of the course and before the exam, students are offered a questionnaire on the evaluation of the course. The comparison among the results of the different years shows that the improvements made are positively evaluated by the students. Figure 9 reports the results of the latest available survey (academic year 2020–2021). Students were asked to evaluate on a four-grade scale the following statements about the course and their involvement in it:

- The preliminary knowledge was sufficient for understanding the topics covered in the course.
- The didactic material (indicated and available) is adequate for the study of the subject.
- The teacher stimulates/motivates interest in the discipline.
- The teacher explains the arguments clearly.
- The supplementary didactic activities (exercises, tutoring, laboratories, etc.) are useful for learning the subject.
- I'm interested in the topics of the course.

Each statement can be evaluated with one of the following points:

- 2.5, strongly disagree;
- 5.0, somewhat agree;
- 7.5, mostly agree; and
- 10, strongly agree.

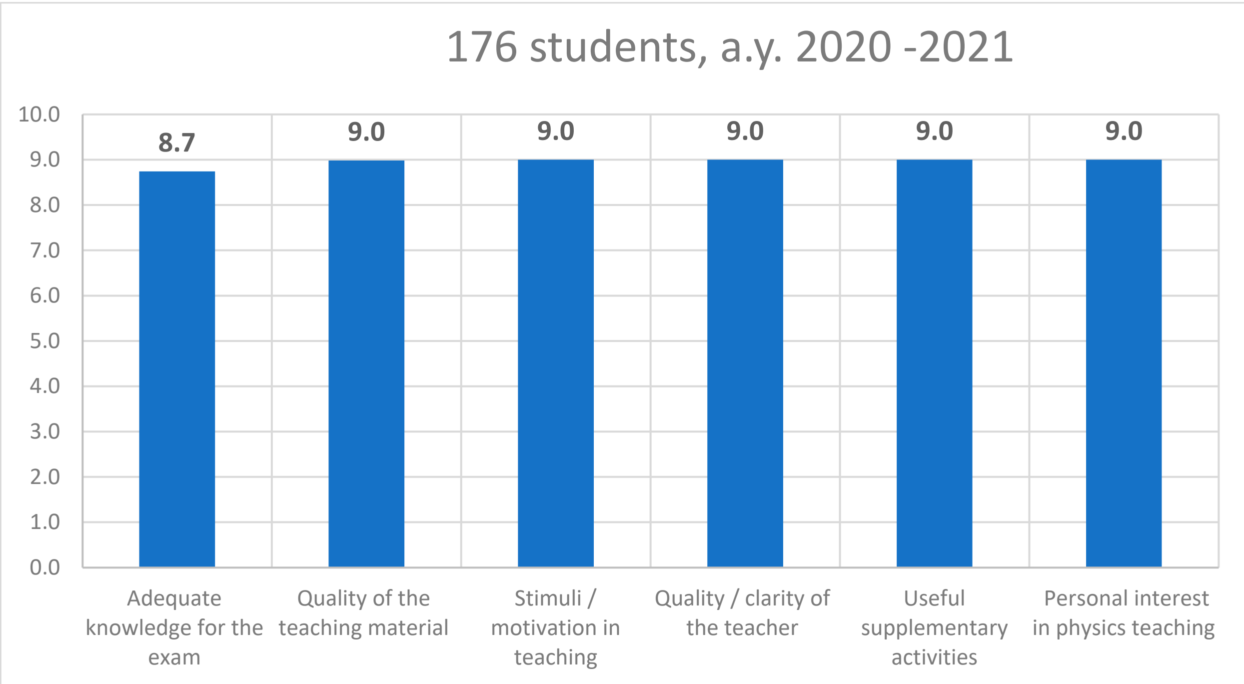

Figure 9. The independent and anonymous evaluation of the course with the responses of 176 students in the academic year 2020–2021 shows that students appreciate the proposed approach.

The results seem quite satisfactory: the average is close to 10 (strongly agree). A comparison among data collected over the years starting from a.y. 2015–2016 shows a progressive increase in satisfaction. This shows that the improvements achieved and the supplementary activities added over the years have produced positive results. The quality of teaching is judged to be very good (questions 2–5), and this is encouraging. In particular, an aspect that seems significant is students' perception about the skills acquired along the course. Students believe they have gained adequate knowledge to take the exam (item 1), and personal interest in physics teaching appears to be truly significant (item 6). To understand the extent of the different perceptions of the subject and the increased self-esteem, it is necessary to refer to the results of numerous surveys that we carried out before the courses. Here, students usually declare that they have not studied physics adequately at school, and that a course demanding the integration of physics content and pedagogical aspects appears too complex and disorienting [42,43].

From students' evaluations, it emerges that the final exam is judged as very demanding. It appears to be in the second position in their ranking for difficulty, the first being that of

"Italian literature", which appears demanding for the extension of the program, whereas the physics exam is considered demanding for its conceptual difficulties.

3.1. Supplementary Remote Support Activities

From March 2020, during the COVID-19 lockdown period, a new mode of interaction was tested between our research group and the students. During this period, 20 h of supplementary activities were carried out involving about 30% of the students on a voluntary basis. In the context of these activities, new study material was proposed, and students were asked to carry out experiences at home, sharing their reflections about them. All the material produced by students is collected in the "Exercises" section of the LES website.

The activities are grouped by thematic areas. Currently (March 2022), there are about 100 student contributions that document both virtual and real experiments (https://phet.colorado.edu/, https://www.vascak.cz/physicsanimations.php?l=it, accessed on 2 February 2022). Students were encouraged to reflect both on their own use of these resources and on the possibilities afforded by them in the school context. In this way, we tried to integrate content relevance and pedagogical aspects by projecting students in their future teaching job. Here, we offer some excerpts from students' reflections that illustrate some lines of thought that have emerged so far. All the quotations have been lightly edited for clarity.

The interactivity and the possibility of practicing at one's own pace were seen as a positive aspect of remote interaction: "The repetition of the test allowed me to pause when I had not fully understood the key points of my difficulties" (Natasha); "the questionnaire with answers and explanations allowed me to understand why my answer was wrong by clarifying some topics" (Carmen). The use of mathematics and physics applets was an opportunity to reflect on one's way of mastering concepts in an unconventional way: "I then tried to create a correspondence between the actions I did in the game with the mathematical operations on functions. I tried to confirm my reasoning [. . .], understanding it was an inverse function. It was at that moment that I appreciated the potential of the applet about functions" (Lucia). Here is an interesting debate about the use of applets in school: "developing didactic activities that can be enriched by a simultaneous and reciprocal use of experiments and applets [. . .]. Applets can also be useful to involve more children with focusing difficulties, remembering and reproducing links with the activities carried out during the day. [. . .] So applets can really represent valid and innovative tools and an excellent way to use technology and make web browsing very productive" (Virginia). Virginia's thinking highlights the extent to which applets can be considered examples of the use of technology to enhance teaching and learning processes.

> "*The use of applets, from the point of view of university students, is useful to the extent that they are used as a theoretical study to verify the knowledge learned. [...] Instead, in school activities, in my opinion, they should be used in a different way depending on the age you are referring to. In primary school, I would always prefer field experiments with everyday objects so that all children can easily reproduce the experiments at home. [...] Starting from middle school, however, applets are an effective tool to make the formula usable, explaining it in small doses, going step by step beyond the mnemonic concepts. Furthermore, in my opinion, starting from this age they represent an excellent self-assessment tool to verify one's knowledge [...]. Starting from the second cycle of education, however, applets are very useful for deepening theoretical concepts [...]*" (Chiara)

> "*From my personal experience, I found their use useful as they helped me understand—and demonstrate—what I previously learned only theoretically. I believe that applets are useful not only for adults but also for children, since digital natives fiddle with technology better than anyone else! Not having the opportunity to experience 'live' [because of COVID pandemic], I really believe that applets are a valid alternative, especially nowadays that technology is part of the everyday life for everyone.*" (Michela)

The debate involved the students on the laboratory experiment–simulation relationship:

> *"[. . .] I also think that the app allows, unlike real experience, to encounter fewer measurement errors, and therefore to have a sort of direct feedback. Playing with the app, I realized how advantageous—in my opinion—the app is compared to a live experiment: sometimes it is not possible to find all the necessary materials, other times we measure incorrectly, but above all it is not possible, live, to think about so many variables at the same time, unless you have sophisticated tools."* (Ilarj)

Perhaps the most interesting and productive part from the training point of view was the experimental activity that was carried out at home (often in the kitchen) with everyday objects. These activities often involved children (children, younger siblings, nephews) and were documented with data, photos, and videos. In some cases, the model related to the phenomenon was also studied with applet simulations. Chiara said: "I put myself to the test by carrying out experiments on heat and temperature . . . . before every experiment there is a lot of reasoning and commitment . . . it was important because this is what I will have to do every day with my students when I teach". Ilarj started from the stimuli of the applets to recognize energy transformation processes at home: "I tried to think about the various energy transformations at home, after using the applet relating to energy transformations, formulating a list of transformations." Clara's testimony is exemplary, documenting the activities with descriptions, photos, and didactic reflections: "I involved my daughters and some friends, I tried almost all experiences with them, so they are not always perfect but I preferred authenticity". In our meetings, we compared the different points of view that emerged from the activities: "From my point of view, the discussion that took place during the exercise lesson was very stimulating and productive because I think that the comparison must be the basis of every activity to encourage an open mind and mutual exchange as well as greater understanding" (Virginia).

For ordinary exams, universities in Italy use a 30-point scale, with a minimum of 18 points to pass the exam. From a detailed analysis of the marks before the distance support activities, with the same number of students, it emerges that the average score increased by 1.2 (from 23.6 to 24.8). This result appears significant if we consider that only 30% of students participated in the (non-compulsory) activities and suggests that the distance support activity, if based on interactivity and continuous feedback, can give excellent results.

3.2. Interviews

Interviews involved 12 students who strongly interacted with our research group during the last year in school and extra-school activities with children and adults (both parents and teachers in in-service training). Detailed reflections on the experiences carried out are reported in their thesis works, available on the LES website (in Italian). The interviews include 10 questions asking to retrace the training activities of their five years of study of primary education and to envisage their future teaching job in light of their experiences last year with our group. For the sake of brevity, the questions and answers are here aggregated into three areas:

1. Training and study in all subjects, and in particular, physics;
2. Experiences with children in the classroom; and
3. Interaction with our research group, cooperative work with other students, and involvement in the training of in-service teachers.

3.3. Physics Classes and Training Course

Feedback about the quality of teaching was substantially positive, but several students complained that most courses neglect the way in which real classroom teaching can be addressed: "There are few courses that deal with teaching in relation to how to teach the different school subjects in the classroom (Daniela)". Indeed, it would be necessary not only to “provide future teachers with a wide-range of knowledge in different fields of study without neglecting practice, i.e., the way in which contents can be addressed in the classroom” (Lucia), but also “with concrete reference to the school world: to understand its operations, how to orient in the post-graduate context with rankings, competitions etc.” (Cristina). The laboratory teaching and the experiences in the classroom in the context of internship were particularly appreciated: “Among the pros, I can certainly mention the various laboratory activities and internship courses that aim to prepare you ‘practically’ for entering the classroom” (Cristina); “The workshops and the internship, above all, were fundamental for my personal growth” (M. Grazia). For the physics teaching course, the answers identified teaching that starts from experiences already tested in class as a strong point: “The course showed how such abstract and difficult topics can become concrete and clearly understandable even to children” (M.Grazia). The reflections on one’s own growth paths appear significant: “The course has rekindled interest in what previous school experience had put to rest [. . .]; I am passionate about it” (Lucia); “It gave me so much confidence in myself” (M. Angela); “I was able to receive important feedback for my training” (Cristina). These testimonies show how in didactic mediation, even at an adult level, learning is the result of a process of resonance between individual cognition, social culture, and structures of reality [5].

3.4. Teaching Experiences

For all the students interviewed, the teaching experiences were significant for their personal and professional growth. An element that was deemed extremely significant is the importance of teaching flexibility, i.e., the ability to grasp the characteristics of the specific educational context at hand: “It helped me to understand how everything can and should be rethought, as the different experiences made in the classroom always have unexpected results, with so many different stimuli leading to different solutions, even unexpected ones” (Teresa); “often one also has to change one’s plan of action. Designing helps but the scheme doesn’t have to be rigid . . . you have to learn to listen to the times of reception, processing and assimilation” (Lucia). Being supported during the first teaching experiences was appreciated by many: “all the difficulties that presented themselves to me never hindered or forced me to stop, but they put a strain on my insecurities but now my self-esteem has improved and I feel stronger and more secure” (Viviana).

3.5. Interaction with Research Group

In the interaction with our research group, peers, and training teachers, the importance of sharing and planning together both in training and teaching emerges. It requires permanent training and self-training activities: “Interacting with each other was also a way to enhance our educational proposals, to encourage us, but also to expose all the concerns, doubts and fears and also to be able to share exciting moments of the practice and the feedback of the children” (Lucia); “Teachers in service have conveyed the importance of work done together, in which each one makes his own skills and knowledge available to the other” (M. Grazia); “During the in-service teachers’ training I certainly understood that you never stop learning and above all that you cannot stop studying” (Viviana). Being included in school activities and the role played by the LES website are recognized as determining factors for professional growth: “The research group has carried out an important mediation work which has made it possible to create a link between initial training and in-service training of teachers” (Cristina); “The LES site has proved to be a place for comparison and professional enrichment due to the many documentation of experiences carried out in the school by the research group and other graduate colleagues” (Lucia). The ability to project one’s future job as a teacher is well summed up in a recurring reflection: “I think that surely now I feel less scared about facing my next work experience, aware of the fact that it is possible to carry out innovative teaching, able to combine the theoretical and practical aspects. I have witnessed the fact that everything could be used as a stimulus for the creation of something new that can contribute to the training of students in a collateral way with respect to the canonical one made up of frontal lessons" (Teresa).

3.6. Focus Group

As described, the physics course is heavily based on the experimental work in schools (production of teaching material, in-service teacher training, pedagogical theorization) that our research group has carried out through the years. In this sense, the course tries to overcome the academic character of the physics course to put the learner in touch with the experiences that take place in real-world teaching. From the first year of the course, our research group has followed about 100 thesis works. In their structure, these theses reflect the way in which the group works on the course: (1) state of the art, with indications from research in teaching and from ongoing experiments, (2) didactic review of the scientific theme, and (3) experimentation in the classroom. As previously mentioned, our research group regularly keeps in touch with trained teachers, many of whom now teach in different Italian cities, mainly in Northern Italy, where there is a greater demand for primary teachers (also due to the greater diffusion of full-time schools). In September 2021, at the beginning of the new school year, we organized a remote meeting with 30 people who graduated with our research group, involving both graduating students and graduated ones who have been teaching for years now. The meeting was also attended by two researchers from a university in Northern Italy of the Faculty of Primary Education interested in studying how we organized our course. The 150-min meeting took place on the Google Meet platform and was recorded. During the meeting, we proposed to organize a self-training course in the school year 2021–2022, with the aim of experimenting in schools the proposals matured in the thesis works. This was the opportunity to share experiences and ideas about the impact of initial training on teaching practice, even after years. Many interventions recalled the first reaction to the physics course: "The physics course was an absolute novelty: weird people who carried so many objects in the classroom. What I would like to highlight is the clear distinction between the course setting and the rest of our university career. I remember all the lessons and the feeling of inadequacy due to the completely different methodology compared to the courses I had followed up until then and also compared to my school experiences with science . . . it is beautiful to apply this 'experimental way' in other areas as well... I still have that critical attitude that I carry over in all situations. It is this attitude that I try to teach my students, following the 'physics style'" (Daniela, 6 years teaching experience); Stefania, who has been teaching for three years, underlines the role played by the construction of the model and the representation of concepts when children discuss amongst themselves: "It was interesting to use this methodology, used both for the thesis work and in the current teaching path. During the thesis it was very interesting to see how to get your hands on concrete facts that then lead to the acquisition of different concepts. The action concerning the reflection on linguistic aspects is correlated to this aspect. It was very interesting to see how children tried to transform their thoughts into a written or iconic form in non-scientific subjects". Katia, who has been teaching for 3 years in a multicultural context, underlines how effective the learned method is, even in complex situations: "I find myself dealing with children who can't speak Italian, so we have organized ourselves in a cooperative work, in small groups. Giving a lot of space to observation and representation is a strategy that works, I see enthusiastic and motivated children [. . .]."

However, not all interventions expressed optimism. In particular, the role played by support teachers was described as frustrating in several cases. Support teachers' role is provided for in the Italian education system, and is described in detail in national guidelines: it consists of addressing, in agreement with the other teachers in the class, all the students in order to carry out teaching that, taking into account the special needs of the children to support, is truly inclusive and to the benefit of the whole class. Among other things, we also experimented with this opportunity in some thesis work, also published on the LES website (Viviana and Lucia thesis in Didactic Resources). To become a support teacher in primary school, it is necessary to follow, after graduation, specific courses and to pass a public competition. In recent years, several primary education science graduates have become support teachers. These are qualified professionals who integrate disciplinary, pedagogical, and neuropsychiatric skills, representing a valuable resource for schools. Unfortunately, this is often not the case: "The first year of teaching made me understand the difference between our expectations and what we can really do in school. You leave the primary training course thinking you can propose many things but then you get to school, where you learn over time, you realize that it is not always possible to put your ideas into practice . . . . As a support teacher it becomes even more difficult because we are seen as second-class teachers, so I feel even more limited. As reasons for the 'no' that the school gives me back, explanations are brought into play on the complexity that the children, whom I follow, would encounter only because my proposal is experimental in character. Those few times that I managed to do something it was nice but it never achieved continuity" (Sara, 6 years teaching experience); "For the past two years I've only been working as support. I emphasize how this is a gregarious role, once I entered the classroom and found my chair already next to that of the child. For me it is a stigma that is given to the child and to the class [. . .]" (Federica, 6 years teaching experience).

Many other interventions addressed the issue of the gap between expectations and school reality, with its problems and constraints. An interesting reflection by Lucia, who just graduated: "I got to conduct [during my thesis] a trial in a fifth class (9–10 years old) where there was a high-functioning child in the autistic spectrum, and I got to see how the use of new technologies together with art and music could give some support in helping her in the relationship. The support teacher of the class certainly helped me a lot also because he viewed me as a novelty, I don't know if it would have been the same if I had been a colleague of his. [. . .]. With the support teacher with whom I collaborated I was able to verify how a specific way of teaching allowed a child with learning difficulties to be able to appear 'less different' to the rest of the class as she was able to participate in the activities. This experience made me understand that when there is an understanding between colleagues, things go well...".

One of the researchers from a university in Northern Italy intervened, showing appreciation for the continuity work with the teaching that is carried out in Naples: "It was really useful to see the willingness to work in a group and continue to share each other after a training course. I also graduated in Education Sciences and I experienced all I heard today, from the enthusiasm of the degree to the impact with school . . . I think it's a beautiful and productive thing . . . . Because the difficulties one encounters are the same as those encountered by others (Lalla, teacher of physics lab at the university)".

Many questions remained open, but we shared the conviction that for the course to have an impact on teaching, participants should be supported by their own school community.

4. Discussion

The article describes a proposal for the initial preparation of primary school teachers in physics that aims to overcome the limits of a purely academic setting. Future teachers are confronted with didactic experiments carried out in formal and informal contexts. The examples proposed aim to show how we try to incorporate concepts and methods of physics into paths aimed at developing skills in teaching and learning concerning science, language, mathematics, physics, and technology.

The course activities are experienced by the research group as a laboratory for didactic experimentation and future teachers are involved in evaluating the effectiveness of the training activities of the course.

Therefore, what seems relevant to us as a matter of discussion is the setting of the course, the way in which the participants are involved, and the strategies aiming at linking the initial training to an in-service one. The ability to teach is not innate, and even if there is passion, motivation, and authentic communication, it cannot be improvised. It requires a long process of initial and ongoing training and interactions with other teachers, educators, and researchers [44–46]. These aspects are often overlooked in educational policies and not taken into proper account in the initial training offered by academic classes.

We think that these issues, touching upon the complex relationship between school and society, must be integral parts of scientific teaching. Sensitivity to these issues, which then allows us to deal with the continuous changes in our societies, must be cultivated already in the initial training of future teachers, and this is at the heart of our teaching practice.

The preparation of primary school and preschool teachers in science is a complex issue that can only be addressed with a systemic vision. As emerges from recent studies and meta-analysis, its complexity and the way to take effective action must involve researchers, educators, and policy makers, and be at the center of both initial and in-service teacher education [2].

In primary school, teachers are asked to tackle a large number of scientific topics, the subject matter being too broad and sometimes unreasonable. The education system should therefore regard teachers as learners both in pre-service and in-service.

A possible solution, both for teaching and learning, to the problem of fragmentation in the exploration of scientific phenomena is offered by the articulated proposals for the science curriculum that collect suggestions from experts in pedagogy and science. In our opinion, the most organic proposal is the one that matured in the continuously updated work of the NRC of the United States [1,2,29,41], which asks to organize scientific teaching in a longitudinal way according to three interrelated lines (core ideas, crosscutting concepts, and practices).

However, many studies show that teachers, in the absence of a continuous educational support, have many difficulties in assuming such articulated points of view [47].

For physics teaching in primary schools, it must be taken into account that many teachers, having the freedom to choose between different subjects, prefer to deal with life sciences and geology, which seem to entail fewer conceptual difficulties [26].

Yet many studies show that children, when they have the opportunity to explore physical phenomena with the support of adults and peers, develop critical attitudes and the ability to work with models and defend their point of view with sophisticated arguments [48–50].

Taking into account the complexity of the problem of teacher preparation and the peculiarities of different educational contexts, we have adopted an action research methodology and the design experiments approach [51] in the organization of the courses, involving future teachers in sharing the strategies adopted. Moreover, this approach is entirely consistent with the need to take into account knowledge, skills, competencies, habits of mind, and beliefs.

We want to emphasize the role that research and experimentation can play in making effective the initial training courses of future teachers, who should be dynamically involved in the activities of our research group, hence the crucial role of field research: all the findings we have reported are constitutive elements of our course.

The course is intended as a didactic research laboratory on how to teach effectively. The research question is inspired by the ideas of Paolo Guidoni, who saw research as an attempt to affect didactic practice, rather than purely academical: "Its aim is to clarify, starting from the phenomenology of explaining-understanding interactions taking place for years within groups of students, two mutually correlated theoretical and practical nodes: how to restructure the Physics's theory presentation to be longitudinally resonant with students' gradual appropriation, in both understanding and motivation; how to infer a cognitive model able to account for success (insuccess) in the school's active mediation, but also to validate planning and support strategies invariant across age spans and different content areas" (workshop July 2019 in Naples).

The Research Group in Didactics of Physics of Naples was formed, starting from the 1970s, by the merging of different lines of research about teaching and learning models in formal and informal contexts, the use of new technologies, and teacher training. The experiences have grown in coordination with national research groups [52–54] and in international projects [55]. Reflections on the experiments carried out and the didactic material produced constitute study material in the training course that we described.

A fundamental role is played in our work by the website "Laboratory for Science Education", which represents a community of practice of about 600 people including students of the course, teachers, researchers, educators, school students, and their families. The site provides a lot of materials for students of the course and allows a link between research and training activities. The community is involved in three interrelated aspects of our research:

1. A modeling of the cognitive dynamics (of children and adults) based on the resonance between "external solicitation" and "internal evocation-response" by a constantly evolving "cognitive system".
2. A "phenomenological approach" (in-depth analysis of what is observed) that goes along with gradual formalization (every type of structured symbolization, from language to mathematics).
3. A systematically long-term interaction with different contexts (classroom, adult education, formal and informal) in which the didactic mediation takes shape starting from the modeling process, and, at the same time, the model itself is built upon the cognitive and operational dynamics that it is able to evoke, develop, and stabilize.

The involvement of future and in-service teachers has allowed us to test some of the key ideas of our approach. The relationship with technology has highlighted the possibility of involving different disciplines at school.

The idea of dealing with physical phenomena by involving students in the analysis of "machines and mechanisms" proved to be effective in our training experience. On the one hand, it has allowed us to "see in action" physical laws, and on the other hand, it has allowed us to share strategies and materials so that the physics mindset can be of some help even in other disciplines. Stefano, who teaches drawing, in a training course intervenes on the proposal we have made on "machines and mechanisms", proposing to try some of the ideas that emerged with his children: "The description of the inclined plane as a machine seems very interesting to me because it actually occurs to me that it was the first building machine. I had never thought of presenting it as a machine from the point of view of the history of art and the history of construction. At school we have an inclined platform for people with reduced mobility." In the next meeting of the same course, he tells how he involved the children at school: "I had good feedback ... I recovered the idea of the definition of the ramp as a simple machine, it could be a topic to be proposed to everyone because from the ramp we talk about the slope (history of construction art), proportions, the Pythagorean theorem, physical mechanism and development of the vine, hilly underground (funicular) ... it is a transversal topic from which to start various virtuous connections ... ". Stefano explains how "another powerful didactic element is that of language. Describing an experience, a fact, with words and drawings becomes almost more important than the experience itself".

The combined use of the virtual laboratory and everyday materials was an opportunity for future teachers to foreshadow their use in their future teaching at school: "Developing didactic activities that can be enriched by a simultaneous and reciprocal use of experiments and applets [...]. Applets can also be useful tools to involve more children who have difficulties in concentrating, remembering and reproducing links with the activities carried out during the day. [...] So applets can really represent valid and innovative tools and an excellent way to use technology to make web browsing very productive" (Virginia). Virginia's thoughts highlight to what extent applets can be considered fruitful examples of technology that enhance teaching and learning processes.

So, how can we prepare teachers to grasp the complexity of their tasks? Several interventions of future teachers who were confronted by teachers in service showed an understanding of the complexity of the role but also the desire to teach by conducting research. "It's necessary to provide future teachers with a wide-ranging knowledge of different fields of study without neglecting practice and the way in which contents can be addressed in classroom" (Lucia, recently graduated), "but also concretely with reference to the school world: to understand its operations, how to move in the post-graduate with rankings, competitions etc." (Cristina, recently graduated). "The research group has carried out an important mediation work which has made it possible to create a link between initial training and in-service teacher training" (Cristina). "The LES site has proved to be a place for comparison and professional enrichment due to the many testimonies of experiences carried out in the school by the Research Group and other colleagues" (Lucia).

5. Conclusions

The goal of linking initial training to in-service training is ambitious, but it is a challenge worth facing. Many graduates followed by our research group teach in various Italian cities (most in the north-central area). From the academic and school year 2021–2022, we have activated a national training course, recognized by the Ministry of Education (https://sofia.istruzione.it/, accessed on 13 February 2022) which involves about 60 teachers in service and 15 undergraduates who are now experimenting in schools of our region with new didactic proposals for their thesis work. The experience of this initiative can be followed by those interested, through the documentation that we publish on the LES website and by asking us for details and more teaching materials.

In the loving memory of Paolo Guidoni. Paolo died on 12 September 2021 and made a significant contribution to research in physics education and to many of the ideas discussed in this article. We wish to dedicate this contribution to him.

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References

1. National Research Council. *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; The National Academies Press: Washington, DC, USA, 2012.
2. National Academies of Sciences, Engineering, and Medicine. *Science and Engineering in Preschool Through Elementary Grades: The Brilliance of Children and the Strengths of Educators*; The National Academies Press: Washington, DC, USA, 2021.
3. Hattie, J. Visible Learning. In *A Synthesis of Over 800 Meta-Analyses Relating to Achievement*; Routledge: London, UK, 2008.
4. Shulman, L.S. Those who understand: Knowledge growth in teaching. *Educ. Res.* **1986**, *15*, 4–14. [CrossRef]
5. Guidoni, P. Re-Thinking Physics for Teaching: Some research problems. In *Research on Physics Education*; Redish, E.F., Vicentini, M., Eds.; SIF: Bologna, Italy, 2004; pp. 223–277.
6. Melo, L.; Cañada-Cañada, F.; González-Gómez, D.; Jeong, J.S. Exploring Pedagogical Content Knowledge (PCK) of Physics Teachers in a Colombian Secondary School. *Educ. Sci.* **2020**, *10*, 362. [CrossRef]
7. Dunst, C.J.; Hamby, D.W.; Howse, R.B.; Wilkie, H.; Annas, K. Research synthesis of meta-analyses of preservice teacher preparation practices in higher education. *High. Educ. Stud.* **2020**, *10*, 29–47. [CrossRef]
8. Cleaver, S.; Detrich, R.; States, J. *Overview of Teacher Preparation*; The Wing Institute: Oakland, CA, USA, 2020.
9. Herbert, S.; Hobbs, L. Pre-Service Teachers' Views of School-Based Approaches to Pre-Service Primary Science Teacher Education. *Res. Sci. Educ.* **2018**, *48*, 777–809. [CrossRef]
10. Russell, T.; Martin, A.K. Learning to teach science. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2007; pp. 1151–1178.
11. Schon, D.A. *The Reflective Practitioner: How Professionals Think in Action*; Basic Books: New York, NY, USA, 1983.
12. Schon, D.A. *Educating the Reflective Practitioner*; Jossey-Bass: San Francisco, CA, USA, 1987.
13. Jones, M.G.; Leagon, M. Science Teacher Attitudes and Beliefs. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Routledge: Abingdon, UK, 2014; Volume 2, pp. 830–847.
14. Ozdemir, G.; Clark, D.B. An Overview of Conceptual Change Theories. *Eurasia J. Math. Sci. Technol. Educ.* **2007**, *3*, 351–361. [CrossRef]

15. Loughran, J.J. Developing Understandings of Practices. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Routledge: Abingdon, UK, 2014; Volume 2, pp. 811–909.
16. Balzano, E.; Cuomo, F.; Minichini, C.; Serpico, M. Communities of practice and continuous teacher professional development. Findings from eight case studies. In Proceedings of the ESERA Annual Conference, Nicosia, Cyprus, 3–7 September 2013; Part 14. Volume 85.
17. Roth, K. Science teachers as researchers. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2007; pp. 1203–1260.
18. Appleton, K. Elementary science teaching. In *Handbook of Research on Science Education*; Lederman, N.G., Abell, S.K., Eds.; Lawrence Erlbaum Associates: Mahwah, NJ, USA, 2007; pp. 493–535.
19. Harlen, W. Primary teachers' understanding in science and its impact in the classroom. *Res. Sci. Educ.* **1997**, *27*, 323. [CrossRef]
20. Crowl, M.; Devitt, A.; Jansen, H.; van Zee, E.; Winograd, K. Encouraging prospective teachers to engage friends and family in exploring physical phenomena. *J. Sci. Teach. Educ.* **2013**, *24*, 93–110. [CrossRef]
21. Riegle-Crumb, C.; Morton, K.; Moore, C.; Chimonidou, A.; Labrake, C.; Kopp, S. Do inquiring minds have positive attitudes? The science education of preservice elementary teachers. *Sci. Educ.* **2015**, *99*, 819–836. [CrossRef]
22. Powietrzynska, M.; Gangji, A. "I understand why people need to ease their emotions": Exploring mindfulness and emotions in a conceptual physics classroom of an elementary teacher education program. *Cult. Stud. Sci. Educ.* **2016**, *11*, 693–712. [CrossRef]
23. d'Alessio, M. The effect of microteaching on science teaching self-efficacy beliefs in preservice elementary teachers J. *Sci. Teach. Educ.* **2018**, *29*, 441–467. [CrossRef]
24. Akerson, V.L.; Elcan Kaynak, N.; Avsar Erumit, B. Development of third grader's identities as "persons who understand nature of science" through a gravity unit. *Int. J. Res. Educ. Sci.* **2019**, *5*, 450–456.
25. Plumley, C.L. *2018 NSSME+: Status of Elementary School Science*; Horizon Research, Inc.: Chapel Hill, NC, USA, 2019.
26. Hammer, D.; Elby, A. On the form of a personal epistemology. In *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing*; Hofer, B.K., Pintrich, P.R., Eds.; Erlbaum: Mahwah, NJ, USA, 2002; pp. 169–190.
27. Louca, L.; Elby, A.; Hammer, D.; Kagey, T. Epistemological Resources: Applying a New Epistemological Framework to Science Instruction. *Educ. Psychol.* **2004**, *39*, 57–68. [CrossRef]
28. Cross, C.T.; Woods, T.A.; Schweingruber, H.; National Research Council. *Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity*; The National Academies Press: Washington, DC, USA, 2009. [CrossRef]
29. Guidoni, P. On natural thinking. *Eur. J. Sci. Educ.* **1985**, *7*, 133–140. [CrossRef]
30. Guidoni, P.; Iannece, D.; Tortora, R. Forming Teachers as Resonance Mediators. In Proceedings of the 29th Conference of the International Group for the PME, Melbourne, Australia, 10–15 July 2005; Volume 3, pp. 73–80.
31. Duensing, S. Culture Matters: Informal Science Centers and Cultural Contexts. *Counterpoints* **2006**, *249*, 183–202.
32. Russo, L. *La Rivoluzione Dimenticata. Il Pensiero Scientifico Greco e la Scienza Moderna*; Feltrinelli: Milano, Italy, 2013.
33. Bellanca, J.; Brandt, R. *21st Century Skills: Rethinking How Students Learn*; Solution Tree: Bloomington, IN, USA, 2010.
34. Clements, D.H.; Nastasi, B.K. Metacognition, Learning, and Educational Computer Environments. In *Information Technology in Childhood Education Annual*; Association for the Advancement of Computing in Education: Waynesville, NC, USA, 1999; Volume 1999, pp. 3–36.
35. Fessakis, G.; Gouli, E.; Mavroudi, E. Problem solving by 5–6 years old kindergarten children in a computer programming environment: A case study. *Comput. Educ.* **2013**, *63*, 87–97. [CrossRef]
36. Trilling, B.; Fadel, C. *21st Century Skills: Learning for Life in Our Times*; Jossey-Bass/Wiley: Hoboken, NJ, USA, 2009.
37. Papert, S. *Mindstorms: Children, Computers, and Powerful Ideas*; Basic Books: New York, NY, USA, 1980.
38. Wing, J.M. Computational Thinking. *Commun. ACM* **2006**, *49*, 33–35. [CrossRef]
39. Ranucci, L. *Arte, Scienza, Gioco. Making E Tinkering Nella Scuola Primaria*; Università degli Studi Suor Orsola Benincasa: Napoli, Italy, 2021.
40. National Research Council. *Learning Science in Informal Environments: People, Places, and Pursuits*; The National Academies Press: Washington, DC, USA, 2009.
41. Balzano, E.; Miele, C.; Merinio, A.; Serpico, M. Primary School Teachers Pre-service Science Learning. The Place of Reflection about Experience. Findings from an Academic Course. In Proceedings of the INTED2017 Conference, Valencia, Spain, 6–8 March 2017.
42. Buccini, D.M. *Educazione Scientifica Nella Scuola Primaria. Modelli Per La Formazione Degli Insegnanti*; Università degli Studi Suor Orsola Benincasa: Napoli, Italy, 2016.
43. Merinio, A. Pratiche di Modellizzazione Fisica e Matematica con Bambini di Scuola Primaria. Ph.D. Thesis, Università di Salerno, Fisciano, Italy, 2018.
44. Mupa, P.; Chinooneka, T. Factors contributing to ineffective teaching and learning in primary schools: Why are schools in decadence? *J. Educ. Pract.* **2015**, *19*, 125–132.
45. Ribosa, J. Review of the book Learning by teaching: Evidence-based strategies to enhance learning in the classroom. In *Innovations in Education and Teaching International*; Duran, D., Topping, K.J., Eds.; Routledge: London, UK, 2021; Volume 57.
46. Kang, H.; Windschitl, M.; Stroupe, D.; Thompson, J. Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking: Instructional tasks and opportunity to learn. *J. Res. Sci. Teach.* **2016**, *53*, 1316–1340. [CrossRef]

47. Ryu, S.; Sandoval, W.A. Improvements to elementary children's epistemic understanding from sustained argumentation. *Sci. Educ.* **2012**, *96*, 488–526. [CrossRef]
48. Watkins, J.; Hammer, D.; Radoff, J.; Jaber, L.Z.; Phillips, A.M. Positioning as not-understanding: The value of showing uncertainty for engaging in science. *J. Res. Sci. Teach.* **2018**, *55*, 573–599. [CrossRef]
49. Kenyon, L.; Schwarz, C.; Hug, B. The benefits of scientific modeling. *Sci. Child.* **2008**, *46*, 40.
50. Cobb, P.; Confrey, J.; DiSessa, A.; Lehrer, R.; Schauble, L. Design experiments in educational research. *Educ. Res.* **2003**, *32*, 9–13. [CrossRef]
51. Balzano, E. II progetto LES: Percorsi di fisica e integrazioni disciplinari su scienza e tecnologia. *Ital. J. Educ. Technol.* **2001**, *22*, 24–32.
52. Balzano, E. *Inquiry-Based Science Education: Perspectives and Difficulties*; Atti della Accademia Nazionale dei Lincei: Roma, Italy, 2016.
53. Balzano, E. La formación científica de base y el rol de la comunidad en relación escuela–familia. *Rev. Int. Magisterio* **2013**, *62*, 68–75.
54. Harres, J.B.S.; Lima, V.M.D.R.; Gessinger, R.M.; Delord, G.C.C.; Balzano, E.; Serpico, M.; Cuomo, F.; Michinini, C.; Breda, A. Processo e heranças de inovação educacional: Legados de um projeto internacional. *Ensen. Cienc.* **2017**, 333–338. Available online: https://raco.cat/index.php/Ensenanza/article/view/334368 (accessed on 12 January 2022).
55. Balzano, E.; Cuomo, F.; Serpico, M.; King, H.; Acher, A.; Dillon, J. *European Pencil Project-Elements of Evaluation of Formal vs. Informal Learning*; CUEN: Napoli, Italy, 2007.