School - University collaboration to train teachers on new topics and new tools in physics education

Marina Serio[0000-0001-9466-3937, 1], Andrea Piccione[0009-0006-5448-3548, 2,3], Tommaso Marino[0009-0004-6377-2291, 4], D Marocchi[0000-0003-1217-4641, 1], Anna Alessandra Massa[0009-0003-6667-8949, 3], Marta Rinaudo[0000-0002-3135-7112, 1], Matteo Luca Ruggiero[0000-0002-1844-5863, 4,5] and Gabriele Scalzo[1]

[1] Dipartimento di Fisica, Università degli Studi di Torino, Via Pietro Giuria 1, 10125 Torino - Italy
[2] Équipe Formativa Territoriale per il Piemonte
[3] Ufficio Scolastico Regionale per il Piemonte, Corso Vittorio Emanuele II, 70 - 10121 Torino – Italy
[4] Associazione per l'Insegnamento della Fisica, Torino - Italy
[5] Dipartimento di Matematica, Università degli Studi di Torino, Via Carlo Alberto 10, 10123 Torino - Italy
[6] INFN, Laboratori Nazionali di Legnaro, Viale dell'Università 2, 35020 Legnaro (PD) - Italy

piccione.eft@istruzionepiemonte.it

Abstract. In-service teacher training must ensure professional development based on both disciplinary and pedagogical research, taking advantage of collaboration between different training and institutional agencies. In this article we will talk about a collaborative experience among different training partners, to increase teachers' interest in new tools and learning environments. We use different kinds of training sessions to introduce innovative didactic methodologies for teaching and learning involving both university research staff and secondary school teachers. The training project has planned a series of five meetings, divided into a seminar and a laboratorial part on the following topics: new didactic technologies, weather data processing, space missions, image processing, and modern physics. The laboratorial workshops were centered on applications that can be integrated into civic education and dual training. The meetings, followed by a hundred teachers, formed a design basis for the initial teacher training courses that will be activated from 2024 by the Italian Universities.

1. Introduction

Education, especially in the scientific field, where a substantial deficiency in the basic culture is detected, depends strongly on teaching professionalism, which determines teaching quality, educational and methodological innovation, as well as improvement of learning [1]. Well-prepared teachers are indispensable to any plans to improve pre-college physics education [2] and the constant and marked changes in the contemporary world mean that teachers must also develop new competencies [3]. The task of the teacher is to offer authentic and engaging learning activities to all the students. Obviously, a strong background in physics is essential, but teachers must also be able to let students grow a sense of curiosity and wonder about the nature and the behavior of physical systems [4]. The skills necessary for establishing a classroom environment that supports inductive reasoning require a deep understanding of the practice as well as the content of the field. [2]. Teachers are requested to become life-long learners to develop students' knowledge in new and actual fields of physics. To teach physics as a process of scientific inquiry teachers must be able to guide students in experiments, collect data relevant to a physical system, analyze those data using a variety of methods, and—based on this analysis— make inferences leading. Most high school physics courses are now—and have always been—taught by teachers who were never specifically prepared for this type of job [2].

Technology development in society requires the preparation of a significant number of physics students. Diminishing interest in scientific studies and lack of enthusiasm for physics courses at school have become international problems. New teaching interventions, promoting active physics learning experiences, are required to promote students' interest in physics. In the development of better physics courses, more attention should be paid to students' gains in the field of reasoning and conceptual understanding [5].

Teachers must be able to use research both in physics and in pedagogy to develop their teaching and provide learning that meets current expectations, like student-active learning. So teachers must be adequately prepared to continuously improve their teaching [6], and programs for initial as well as ongoing training are essential. There is the necessity to complement the teachers' disciplinary command with pedagogical competence to facilitate the development of high-level competencies in their students. Motivation to learn, creativity, and cooperation seem to be crucial [3], but it is also important to offer competencies in new, modern topics. So, Physics Departments must be involved in this process [2].

In education, emerging technologies have also been transforming ways of teaching and learning. With the thrive of AI technology, its applications in education have been increasing. The increasing applications of AI in education (AIEd) demand interdisciplinary approaches to build a deeper understanding in AIEd, including its current state, potentials, challenges, and future directions [7]

Teaching in physics courses at all levels should be informed by findings published in the physics education research literature [8]. The Resource Letter—PER physics education research, published in the American Journal of Physics [9], has the purpose of providing an overview of research on the learning and teaching of physics to the large community of physics instructors whose primary interest is in using the results from research as a guide for improving instruction [10].

In general Physics Departments should recognize that they have a responsibility for the professional preparation of pre-service teachers [2] and their update. The professional development of Italian in-service teachers is not structured in a coherent and stable institutional network; it has been implemented in different ways and isolated projects [11, 12], although of quality. In recent years, the Physics Department of the University of Turin has experimented with different types of training activities in service: workshops, conferences, seminars, and laboratory sessions. These activities have created relationships and exchange networks with teachers, associations, and institutional school structures [13, 14]. During the COVID-19 pandemic phase, the collaboration allowed to support teachers in the development of online teaching activities of physics, sharing skills and experiences, especially regarding the use of ICT. This network of personal and professional relationships is the natural habitat of a training project dedicated to second-grade secondary school physics teachers.

This is the context of the current project, which is also motivated by several well-established factors. These include

- the need to bridge the gap between research and teaching-learning practices;
- the development of tools and resources that anyone, not just expert teachers, can utilize;
- the emergence of new scenarios due to rapidly advancing technologies.

To achieve these goals, it is essential to enhance collaboration among different entities, each with its unique expertise: universities for research in physics and teaching methods, expert teachers for learning practices, and teacher trainers for new technologies. This collaboration is crucial for promoting digital citizenship, fostering a culture of science, and harnessing the potential of these new technologies as powerful tools for teachers. The project has been presented already in [15], where we focused mainly on tools; here we will discuss the collaboration among entities, the design of teachers' training, and the implementation of classroom activities.

2. Focus on the training project and the players

Producing well-qualified teachers is a complex task that involves college and university faculty, experienced teachers, and school administrators. The process of becoming an effective teacher continues through early mentoring and ongoing professional development [16].

Unfortunately, physics faculty members are rarely involved in teacher preparation [17], but fortunately, many different formative strategies and methods for teachers' professional development are thought of and presented in international meetings [18].

Ongoing teacher training in Italy is regulated by the National Collective Labour Agreement, which establishes training arrangements and training subjects, like educational institutions, universities, and institutions of higher artistic education, music, and dance.

The proposed training activities are communicated and made available on platforms that allow the recognition of the educational commitment since the teachers participating in the training activities are considered in full service.

In 2023 we decided, as members of different educational entities, to design a collaborative training path to achieve an important synergy between teaching and research in Physics.

The subjects involved are:

- Physics Department of Turin University, in particular the Didactic and History of Physics research group, for which the project falls within the framework of Public Engagement as an action of dialogue and collaboration between researchers, students, and teachers of the territory for the introduction of active and innovative didactic methodologies, reconfiguring the spaces and times of teaching and learning.
- The Regional Education Office (USR), which supports organizational flexibility, teaching, and educational research and gathers local needs to create training opportunities. In addition, it takes care of the organization and diffusion of courses and resources.
- The Territorial Training Équipe (EFT) of Piedmont, which promotes and supports the experimentation of new organizational models and innovative teaching methodologies and the development of digital education projects, digital citizenship, media education, and Artificial Intelligence (AI). It also promotes, supports, and follows the design and implementation of training courses for teachers on the digital transition.
- The Association of Physics Teachers (AIF), dealing with physics and, in particular, with the teaching of physics and sciences - at the level of secondary schools of the first and second grades and of the University. The association prints and disseminates scientific, educational, and cultural publications and organizes refresher courses, teacher training, summer and winter schools, conferences, seminars, and competitions for teachers and students.

After several years of distance training, we wanted to propose conducting in-person training to strengthen relationships among teachers. The project was not intended for a systematic analysis of outcomes; instead, its purpose was to test the format and tools and to gather participant feedback for designing future training sessions. The teacher training project was structured into five sessions, each consisting of two distinct parts. The first part featured seminars presented by scientific researchers on recent topics. These seminars were held in person in Turin but were also accessible to anyone in Italy through live streaming. The second part involved a hands-on laboratory session where experienced teachers guided participants in experimenting with various tools and activities. Participants could optionally receive further support from a trainer in their classrooms after the sessions. The first two meetings took place at the Physics Department, while the last three were hosted at a secondary school to emphasize the collaborative role of both universities and schools in teacher training. Participants were

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encouraged to bring their laptops, allowing them to experiment with the tools in a familiar environment and easily save their work for future use.

3. Topics and tools

This part will include some examples from the training activities. According to a recent survey conducted by the Italian Physics Teachers Association [19], the training courses that teachers are primarily interested in are focused on various aspects of modern Physics. These topics range from space missions and astrophysics to quantum mechanics, as indicated in their report. Regarding tools, the survey highlighted a significant interest in acquiring knowledge related to data acquisition, including microcontroller development boards, sensors, and other relevant resources.
We began by addressing the needs of the teachers from the initial survey, then we added their feedback from each training session. The main goal was to make the subsequent work with students easier and to present activities ready to use in the classroom; for this purpose, we searched and chose the most appropriate tools and subjects. The suggested activities were initially created for the teacher training course. However, these activities are versatile and adaptable to be used directly with students as well. Teachers can adjust the activities to meet their classroom needs, making them suitable for engaging students in various learning experiences. The full list of seminar topics and the list of workshops and tools presented had been discussed in a previous paper [15].

Each meeting was attended by about 30 teachers for the seminar part and 15-20 for the workshop. Fifty percent of the participants attended 2 or 3 meetings and less than 10 percent the entire training. One difficulty, perceived through the evaluation questionnaire, was precisely the participation in a program with a calendar extended over about 3 months. In addition, the last two meetings had a lower frequency, although the topics were considered interesting, due to the schedule in the school year. The modality of the streaming seminar and in-presence workshop was judged satisfactory by 85 percent of the participants: the criticisms concerned the non-usability of the laboratorial part, carried out in presence. We want to discuss here in particular two topics, which were found to be of general interest. The first topic is the application of Artificial Intelligence to Astronomy; the second topic is Relativity, and the suggested activity was the subject of a dissertation in Physics Education.

3.1. AI tools applied to Astronomy: from teacher training to classroom activities

In our activity, two out of five meetings were devoted to Astronomy. In the first meeting, the discussion focused on hints and updates from research, specifically on data from space missions. The presentation mainly covered data from the Rosetta @ 67P and NASA DART missions, as there are many images available from these missions that are engaging for both teachers and students. The second meeting showcased the application of AI in Astronomy. It began with a brief introduction to AI, highlighting the differences between supervised and unsupervised learning. An overview of AI applications in event reconstruction, detection and tracking, and imaging was presented. The seminar went into detail about the Fermi LAT experiment, emphasizing the use of AI tools in event selection to distinguish the electron signal from the hadronic background. It was shown as a supervised learning technique compared to an unsupervised one. In the first case, we have human-labelled data with a strong dependence on models and simulations, which are an imperfect reproduction of reality and could thus introduce huge systematic uncertainties or biases. In the second case, there is no need for pre-existing labels, and only minimal human supervision is necessary, which helps to reduce uncertainties.

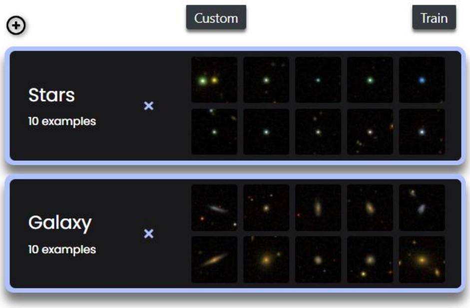

Figure 1. Exercise with the Classifier of the AppInventor project [26] to the classification of stars vs. galaxies: images used to train the model. The exercise is the same as [15], but it is made with a different tool.

Figure 2. Exercise with the Classifier of the AppInventor project [26] to the classification of stars vs. galaxies: prediction of the model on test images, the percentage indicates the accuracy of the result.

The second part of these meetings was devoted to tools and suggestions from expert teachers. In one case, given the growing interest in virtual assistants, we showed an application for them in space missions. We utilized Picroft [20], a ready-to-use text-based assistant that runs on a micro-computer like Raspberry Pi. The demonstration included examples of interaction with the assistant and training it to support people on a space mission. The aim was to make the participants aware of the power and limits of virtual assistants. The presented tool may present some difficulties since it has a Linux-based text interface. However, it works offline, is highly customizable, and allows for better handling of privacy and data problems that arise with other online tools of the same kind.

Tutorials and classroom-ready activities that explore many deep sky objects have also been generated [21]. As an update on these activities, we have integrated AI into sky exploration. Several tools are available for implementing AI applications in astronomy [22, 23]; however, they can be challenging for non-expert teachers to use. In the second meeting, we presented some ready and easy-to-use applications for Machine Learning, such as TeachableMachine [24], MachineLearningForKids [25], or appInventor [26]; they were applied to a simple example of classification like stars vs. galaxies. These tools provide a framework to build a supervised machine learning model, with some predefined parameters. The user needs to define two or more classes and load the images in the corresponding class (figure 1); after a training process a model is created, and its predictions can be tested with images that were not included in the training set (figure 2). In this case, a dataset with a small number of images had been selected from the SDSS archive [27]; selecting images for use in teaching is easier with this archive than with others. Some more complex tools such as computational notebooks were also shown. In this case, the Python programming language has been used, and it was shown as an example to distinguish ten different kinds of galaxies [28].

The project included an optional supporting phase in the classroom for interested teachers. We present an example of an activity that we implemented. The class was selected based on the amount of available time at the end of the school year, which is often a limiting factor when trying out new activities in classrooms. In our case, the class was chosen also because students had already been introduced to astronomy during their regular lessons. The class was composed of students in their final year of high school, and the presentation on AI could potentially impact their prospects. Moreover, students had a limited physics curriculum and no coding experience. Together with the teacher, we planned to focus on image classification to present tools that are useful in other disciplines, such as art. Our main goal was to not only give students some ideas about AI basics but also let them experiment with machine learning to understand its power and limitations. We mainly tried finding resources and techniques to explain AI in simple terms.

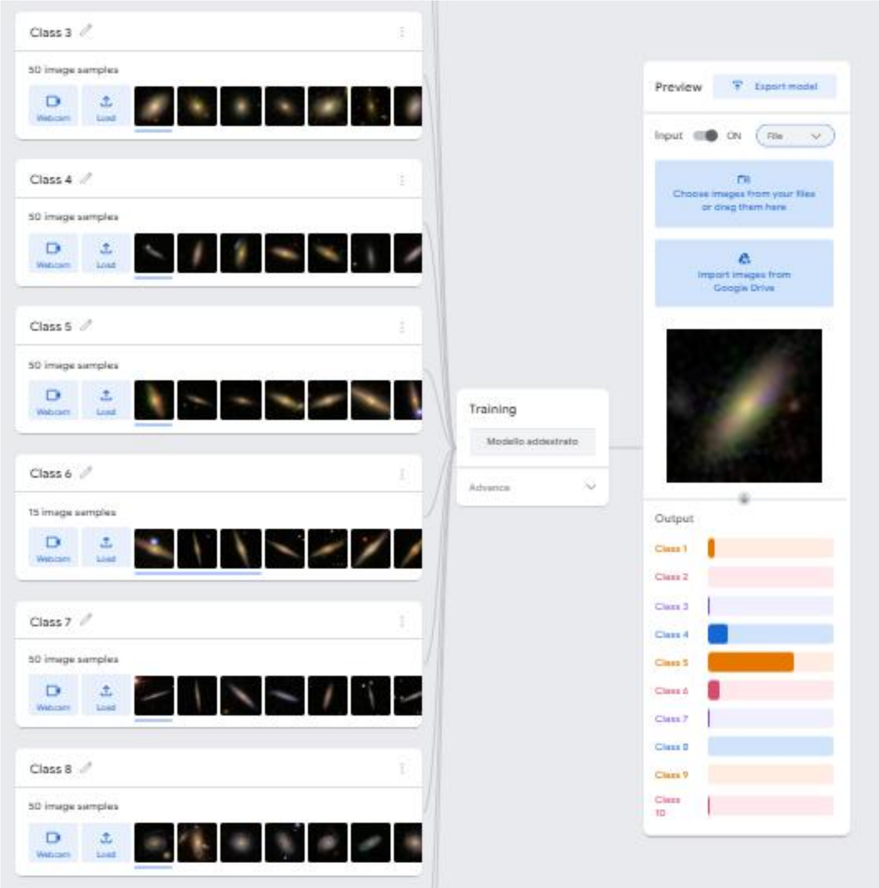

Figure 3. Application of the Teachable Machine [24] to the classification of different kinds of galaxies. The result of a test image is given as a percentage of each available class. The same dataset used in figure 6 of ref [15] was used but with a simpler tool.

The classroom activity was a two-hour lesson divided into three parts. At the beginning, a brief introduction to AI focused on the differences between classical models and machine learning models, which are based only on correlations. The spurious correlations project [29] offers many hints to discuss this issue. In the second part, students were introduced to a ready-to-use tool for image classification, such as TeachableMachine, and were asked to train a Machine Learning model in two steps. First, they were tasked with using the same example used in the teachers' training to distinguish between stars and galaxies. The tool they used was easy to operate, and all of them completed the exercise within the given time. For the second exercise, they were given a task involving ten classes of galaxies. To facilitate the students' activities, especially considering their lack of programming knowledge, the Teachable Machine was implemented also in this case instead of the Python notebook used in the teachers' training (figure 3). In the third part of the lesson, AI and astronomy were combined with storytelling. Indeed, the classification of celestial bodies can be used in both scientific and narrative contexts. In a training project called InnovaMenti_TECH [30], one of the activities in the AI module was to write the continuation or the end of a story based on the outcome of a classification. The goal was to highlight certain aspects of Machine Learning, including the potential effects of inappropriate training. In the book "George's Secret Key to the Universe" by Lucy and Stephen Hawking, a supercomputer opens portals to access parts of the universe. The teaching proposal is to prompt students to write a passage on how the story could continue based on whether they arrive near a single star or in the middle of a galaxy, in the scenario where the supercomputer has been trained with images provided by the students. Even though the students appreciated it, this last part was not completed due to lack of time. At the end, the teachers were asked to fill out a feedback form, where it turned out that the language used was clear and simple, and that the tools were easy to use for both exercises (figure 4).

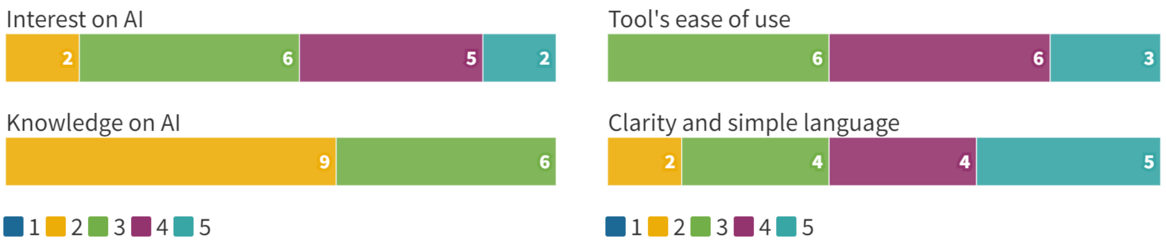

Figure 4. Results from the students' feedback. The numbers indicate the total of answers for each value of the Likert scale from 1 to 5. Even if their interest in AI is high, they have poor knowledge of it.

3.2. *Relativity*

We establish the context by presenting findings from a recent graduation thesis [31] survey that delves into creating instructional materials for teaching General Relativity (figure 5). The survey, which involved 109 high school teachers from all over Italy, queried educators regarding their proficiency in modern Physics, particularly General Relativity. The results revealed that a significant number of teachers do not feel adequately equipped to introduce such topics. Notably, a considerable portion of them acquired competence through self-study, with only a minority benefiting from specific teaching programs.

During the initial segment of the training session, we introduced an interactive web-based platform designed to elucidate concepts related to Relativity [32]. Inspired by Einstein and Infeld's "Evolution of Physics" [33], this platform offers a systematic conceptual progression, commencing with Galileo and Newton, to instil the foundational principles of General Relativity and to emphasize the impact of Einstein's theory on our lives, through its relevance for current positioning systems. Accordingly, the relativity of time was the key topic of the training session.

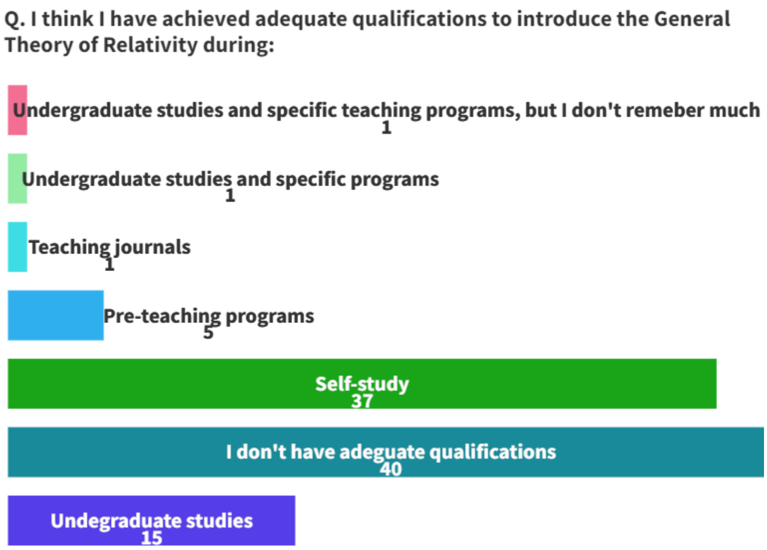

Figure 5. Most educators express a lack of confidence in their ability to teach General Relativity, either stating that they do not possess the necessary qualifications or that they have obtained competence through self-study. This underscores the importance of implementing training programs specifically tailored to address this gap in qualifications. Results are expressed as a percentage of the total number of answers.

The practical component of the training centered on utilizing online maps to assess the impact of relativistic corrections on GPS accuracy [34]. This approach drew inspiration from the Einstein-First project [35], an international research collaboration committed to incorporating key concepts of modern physics across educational levels [36]. Figure 6 illustrates an exercise assignable to students, prompting them to determine the GPS destination that would be indicated if one or more relativistic corrections were overlooked. This exercise is crucial for grasping the significance of Einstein's theory in daily life. The concept is straightforward: navigating from the yellow starting point to the red destination is the objective, but neglecting relativistic corrections significantly diminishes accuracy, rendering it impossible to discern the true destination.

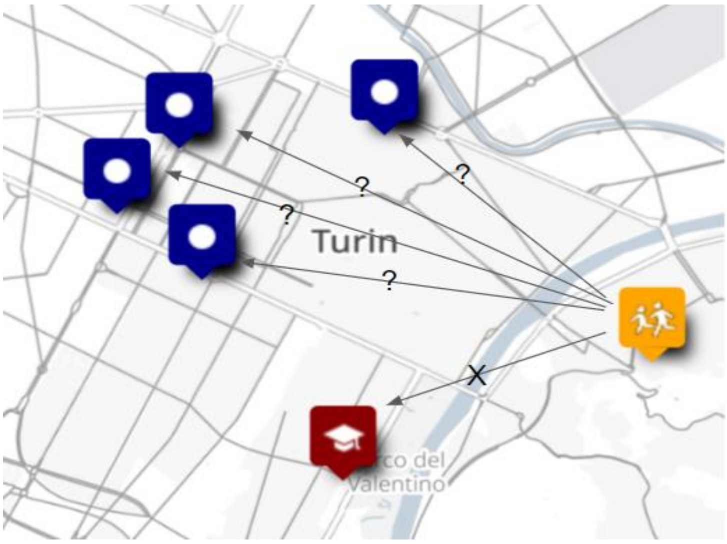

Figure 6. Disabling relativistic corrections leads to a significant decline in GPS accuracy. Consequently, our awareness of the destination's position (depicted in red in the figure) diminishes, increasing the likelihood of inadvertently arriving at undesired locations (depicted in blue in the figure) [15].

4. Conclusions

The project had a good response from participants, for the online seminar part. The satisfaction online questionnaire reports a level of liking, on a Likert scale from 1 to 5, between 4 and 5 for 70% of the respondents. The designed training activity had only one limitation: the difficulty of scheduling participation over three months, with work commitments or other problems that may arise. On the usability of what was acquired in the laboratory part, we noticed that the option "interesting, to be explored further" prevails over the option "easily usable/integrated into the lesson" for all the technologies illustrated in the meetings, except for RelActivity, where the proposed activity seems more directly workable in the classroom. The activity that seemed most difficult to apply or judged by some as not applicable in a school lesson, is the one on virtual assistant simulators. This assessment is a sign that these technologies need basic educational research on their potential, appropriate reflection on their use, and the development of appropriate and open-access teaching proposals for less experienced teachers.

The most important result of our project is that the training entities of the various institutions have created a network of relationships crucial for initial teacher training, legislatively defined by the Italian government decree in the summer of 2023. The current incoming teacher training program includes a course of 60 ECTS, 16 dedicated to disciplinary teaching methodologies. In the design of the disciplinary ECTSs, we give ample space precisely to some of the topics and technologies tested during the course, to help future teachers to set up their teaching actions from the very beginning, according to the latest research. Actually, 7 over 16 ECTSs are dedicated to these topics.

The laboratory activity also highlighted a need for training and acquisition of skills from an IT perspective, as well as the need for sharing resources and their usability. In the future, we plan to intensify and broaden our collaboration efforts aimed at providing in-service training for teachers. This partnership will focus on offering teachers' continuous professional development opportunities to keep them up to date with the latest teaching methodologies, technologies, and educational practices. Future

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classroom activities will be designed to systematically collect data to assess their impact on attitudes in physics and new technologies.

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