PAPER • OPEN ACCESS

Training teachers on new topics and new tools in Physics education

To cite this article: A Piccione *et al* 2024 *J. Phys.: Conf. Ser.* **2693** 012010

Training teachers on new topics and new tools in Physics education

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Abstract. We report the result of a collaboration among Universities, Schools, and Institutions to increase interest in new tools and learning environments. To address this issue, we provide scientific and didactic support to teachers through different kinds of training sessions to introduce innovative didactic methodologies for teaching and learning. The project involved a training course both in streaming and carried-out sessions with university staff as well as secondary school teachers. We selected current research such as climate change, space missions, and Einstein's relativity since they are not commonly included in the Italian physics curriculum; we suggested an approach based on some new methodologies and technologies to introduce these topics. We used microcontroller development boards for measuring environmental parameters, Artificial Intelligence (AI), and data processing applied to Open Data from space missions or weather archives. We also suggested a new approach to teaching modern physics. For this purpose, we used a web-based platform to explore the basic concepts of relativistic physics by emphasizing its impact on Global Positioning Systems, which is of utmost importance in everyday life.

1. Introduction

The ongoing training of teachers is the most relevant tool for the updating and professional growth of the teaching staff. There are different actors and different scenarios in which this training takes place.

In Italy, universities often support Regional School Offices in training activities, which implies the possibility of involving teachers in training linked to scientific research developments, and the methodologies and technologies developed and used in research. In Turin in 2023, gathering a tradition of educational proposals for high school Mathematics and Physics teachers, a series of seminars and laboratory sessions were planned and realized by actors from different institutions: the Physics Department (Univ. Torino) [1], the Regional Education Office (USR) [2], the Territorial Education Équipe (EFT) of Piedmont [3] and the Association of Physics Teacher (AIF) [4].

The chosen title "New Topics and New Tools in Physics Education" summarizes the motivations of the project. Some of these motivations are well known, such as the need to bridge the gap between research and teaching-learning practice at all levels as well as the need to implement tools and resources that anyone can use (not only expert teachers). Above all, there are some new worldwide and European scenarios due to technologies that are emerging very fast:

- the 2030 Agenda for Sustainable Development [5], with particular attention to Goal 4 Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all: b) "…for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programs, in developed countries and other developing countries"; c) "substantially increase the supply of qualified teachers, including through international cooperation for teacher training in developing countries, especially least developed countries and small island developing States".
- the European Digital Education Action Plan (in particular Action 6-Ethical guidelines on the use of AI and data in teaching and learning for educators [6], and Action 8-Updating the European Digital Competence Framework to include AI and data-related skills [7])
- The National Recovery and Resilience Plan/Next Generation EU program [8], with the missions "STEM skills and multilingualism for teachers and students" and "School 4.0. Innovative schools, wiring, new classrooms, and laboratories".

Finally, at the national level, the government has launched the reform of the teacher recruitment system and of the initial and ongoing training. The concrete implementation of this new regulation will require a strong commitment of university and school institutions, in light of the new educational objectives that current educational research and modern technologies allow to identify.

2. The project

A recent survey made by the Italian Physics Teachers Association (AIF), answered by a sample of 915 teachers, pointed out that the topics in which teachers are primarily interested for a training course are all related to modern Physics, from space missions and astrophysics to quantum mechanics and relativity, as you can see in figure 1 (in Italian as in the original report, but easily understandable); on the tools side, the main interest is in all those which are needed to data acquisition, as microcontroller development boards, sensors, etc. We have considered the suggestions stemming from this survey to choose the topics on which the training project is centered, focusing on secondary school teachers.

We planned a series of five meetings, lasting approximately three hours, each divided into two parts. In the first part, scientific researchers gave a seminar on some recent topics; these seminars were carried out in presence in Turin, but they were open to anyone in Italy and broadcasted via streaming. Secondly, after the seminar, a laboratory activity was scheduled. Here, some expert teachers had the participants experiment with some tools and some activities. Teachers were asked to carry their laptops to let them experiment with the tools in their working framework and easily save their work for future activities. Thirdly, optionally, the participants could be supported by an équipe member in their classroom after the meetings. The first two meetings were hosted at the Physics Department, while the last three were hosted in secondary school to enforce the dual role of University and Schools in teachers' training. In the registration form, teachers selected the meetings they were interested in; we had about 100 registered teachers, the average participation was 30 teachers per meeting.

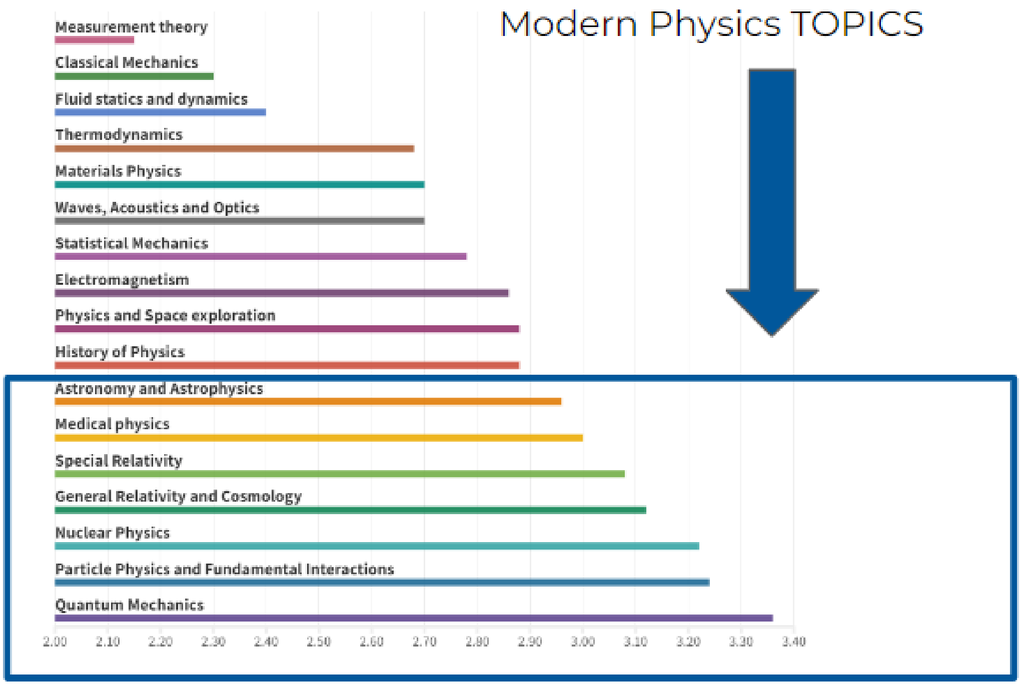

Figure 1. Results of the AIF survey on disciplinary skills. The most voted skills are (in ascending order): physics and space exploration, astronomy and astrophysics, physics and medicine, special relativity, general relativity and cosmology, nuclear physics, particle physics and fundamental interactions, quantum mechanics.

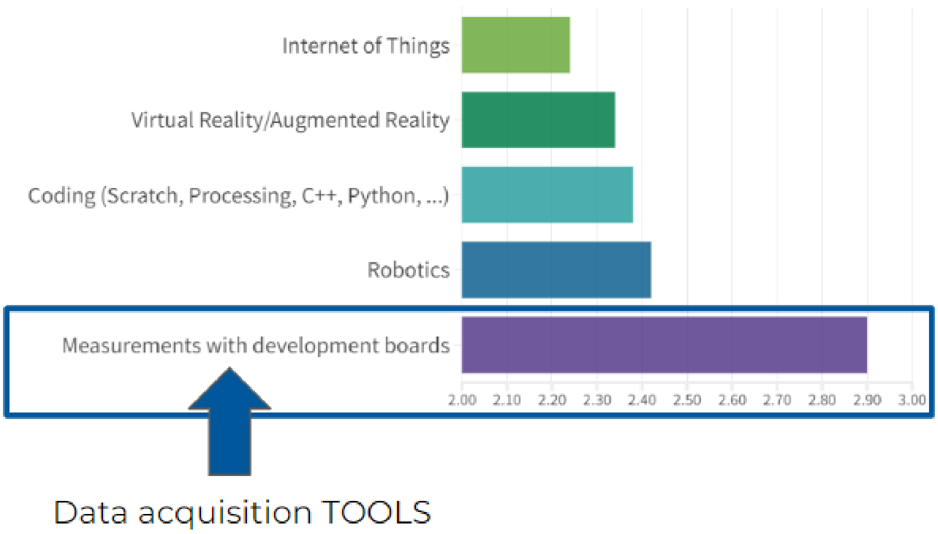

Figure 2. Results of the AIF survey on technological tools applied to teaching physics. The most voted tool is data acquisition with microcontroller development board.

3. Tools and topics

In this section we will show some examples taken from the training activities; we describe how we started from the teachers' needs, and their step-by-step feedback after the training sessions. The main interest was to identify proper tools and topics, to ease the subsequent work with students; thus, in the following we address the activities to teachers, but they can be repeated with students as well. The following is the complete list of the seminar topics:

- Physical Computing, STEM and educational robotics (D. Grosso, Univ. Genova)
- Meteo-Climate Data acquisition and analysis (E. Palazzi, Univ. Torino.)
- Data from space missions: Rosetta @ 67P and NASA DART (C. Tubiana, INAF-IAPS)
- Data from space missions: Fermi LAT and AI (R. Bonino, Univ. Torino)
- RelActivity: an interactive path to teach Relativity (M. L. Ruggiero, Univ. Torino)

Then, this is the list of the workshop tools:

- microcontroller development boards (T. Marino, S. Falabino, S. Coscia, G. Saglietto)
- spreadsheet and notebooks for data analysis (A. Piccione, A. A. Massa)
- virtual assistant simulators (T. Marino)
- AI tools to classify images (A. Piccione)
- GPS and General Relativity (G. Lombardo)

In the following subsections, we highlight on some of them.

3.1. Microcontroller development boards

Educational applications of microcontroller development boards are spreading more and more, and they are used in many Physics measurements [9]. In our project, we did not focus on one board, but on their potentialities; indeed, these devices offer the possibility of having the same framework to make different experiments with a low budget. Teachers have to practice with the Integrated Development Environment (IDE), where they write and debug the code; these environments can provide visual/block programming or text programming. In the first steps they can start with very simple projects; once they become familiar with the IDE and the way of programming the board, they only have to change the sensor, and are able to measure many different quantities. Most sensors are cheap and can be easily found.

In the laboratory part, some applications were practically experimented with by teachers, choosing from a set of possible measurements: temperature, light and sound intensity, time and distance, acceleration, magnetic field, and environmental parameters. As an example of experiments that can be realized with a low budget, in figure 3 we show a micro:bit board [10] used to measure rotational acceleration with a salad spinner. This kind of board is suitable for introducing activities for kids or students with low knowledge of programming and circuits [11].

In figure 4 we show a simulated Arduino setting to measure the light intensity as a function of the distance. Arduino boards are more complicated than the micro:bit ones, but they are powerful because they give the opportunity to implement complex measurements: almost all the sensors have libraries compatible with the IDE, and teachers can customize the measurement settings. In order to ease the introduction of these boards, we started from a virtual laboratory framework, where teachers do not take any risk of making some incorrect connections or code mistakes. Different kinds of virtual laboratory tools are available: some of them support many boards, as well as programming languages from blocks to Python and Javascript. Once they practiced on the virtual boards, teachers can start working with the real ones.

The main problem we encountered in the training was the lack of programming skills by teachers. The reason could be due to the absence of coding in the undergraduate studies of many teachers, as well as to a low use of in their job/teaching activities. The possibility of using a visual/block programming language can simplify filling this gap of knowledge and experience; however, this remains a crucial issue in teacher training.

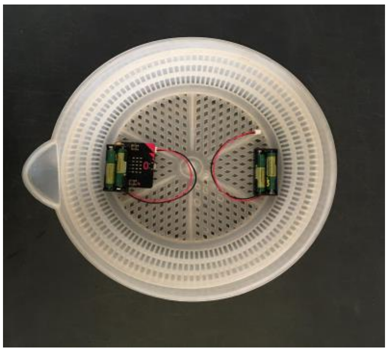

Figure 3. The experimental setting to measure the rotational acceleration with a micro:bit board and a salad spinner. micro:bit can be programmed with a visual/block language, but also in Python and Javascript. It offers the possibility of implementing online classrooms, where students can experiment with the code. The battery in the right part of the picture is needed to properly balance the spinner during rotation.

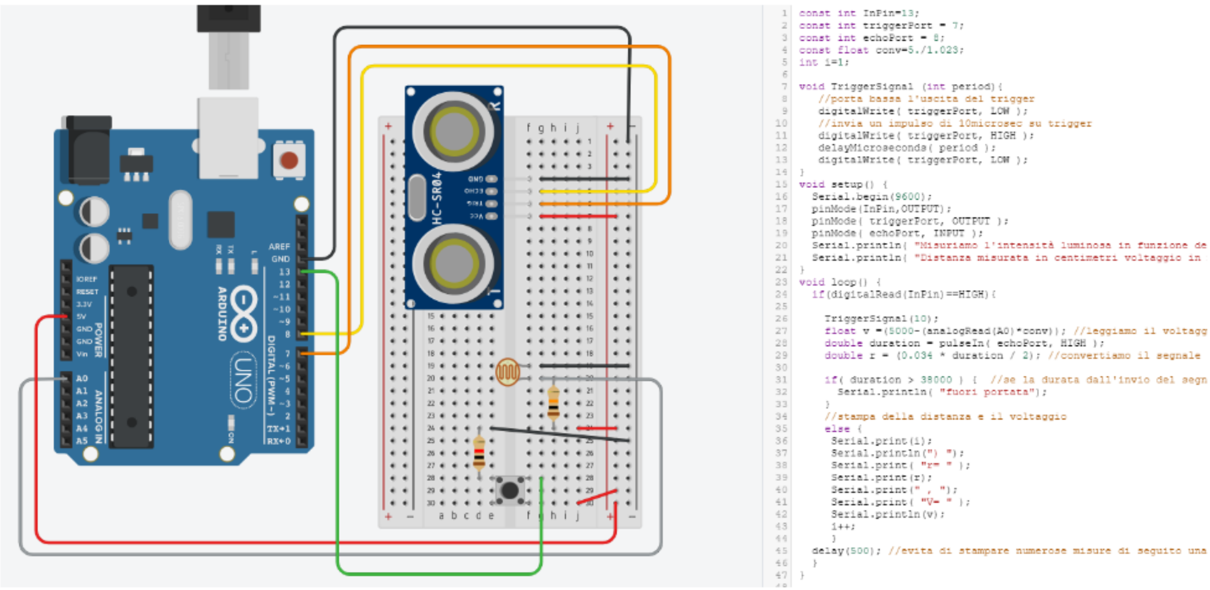

Figure 4. Simulation of an Arduino board to measure the intensity of light as a function of the distance between the sensor and the light source. A HC-SR04 ultrasonic sonar distance sensor and a photoresistor are used in this case. On the left there is the simulation of the hardware, and on the right the code that is needed to control the data acquisition.

3.2. *Artificial intelligence and astronomy*

AI is a trending topic in everyday life, but it also has many applications in physics research; since astronomy and astrophysics turned out to be relevant topics in the survey shown in figure 1, we decided to show some AI tools to classify images from astronomy.

In the initial part of the training session a researcher introduced AI, with particular attention to the differences between supervised and unsupervised learning. Then, an overview of applications was shown as event reconstruction, detection, tracking and imaging. As an example, we discussed the application of AI techniques in event selection of the Fermi Large Area Telescope experiment [12].

The second part of the session was devoted to tools and suggestions from expert teachers, with the aim of experimenting the main features of machine learning (ML). Given the difficulties with programming languages encountered in the training on development boards, we selected some ready and easy to use applications such as Teachable Machine [13], MachineLearningForKids [14] or appInventor [15]. These tools require a very low effort to be used: a set of images have to be uploaded on an online environment, and the user needs to divide them in two or more classes; then the ML model is created with a predefined setting, and it can be tested to classify images not included in the initial set. As a simple example of an application, we choose the classification of stars vs. galaxies (figure 5); we used the SDSS dataset [16] since it is easy to use for educational purposes.

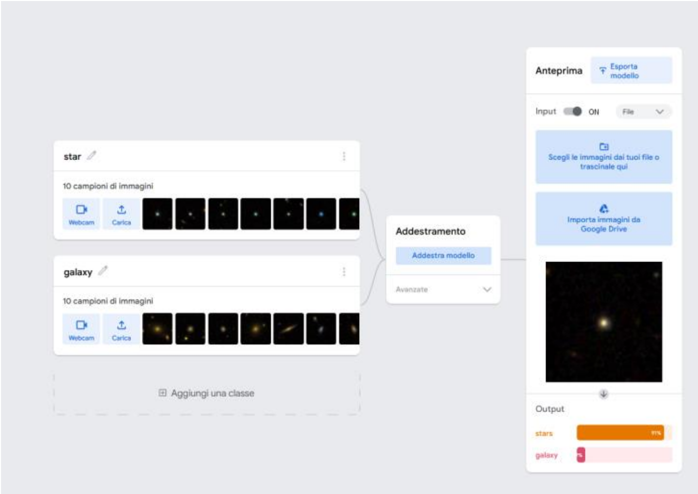

Figure 5. Application of the Teachable Machine [17] to the classification of stars vs. galaxies.

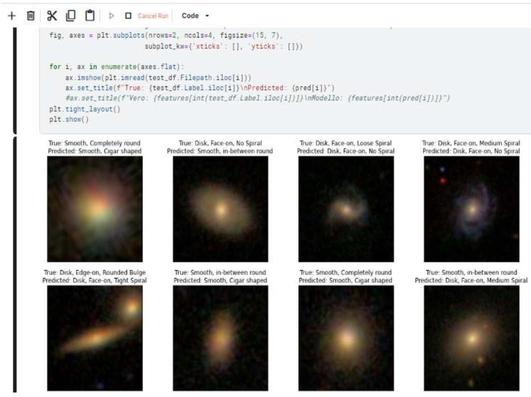

Figure 6. We show the model's prediction when it is initialized randomly. Using Jupyter notebooks it is then possible to set all the parameters of the algorithms and investigate details of how they work.

Jupyter notebooks are widespread in research activities, and they can be powerful tools in teaching as well. They need some knowledge about programming, but they provide many opportunities: customizing applications freely available online, introducing students to tools used in scientific research and to better understand how machine learning works. In figure 6 we show a notebook written in Python with an example to distinguish 10 different kinds of galaxies [18].

Finally, we presented an application of virtual assistants to space missions as an introduction to these tools given the increasing interest in generative applications of AI. The selected tool has been Picroft [19], which is a ready way to use an assistant on a micro-computer like Raspberry Pi.

3.3. General Relativity

We define the context by showing another survey from a recent graduation thesis, whose focus is the production of resources for teaching General Relativity. Teachers were asked about their competence in modern Physics with a focus on General Relativity, and it turned out that many of them do not feel qualified to introduce such topics. We can also observe that many of them achieved competences by self-study, and only a few of them thanks to specific teaching programs (figure 7).

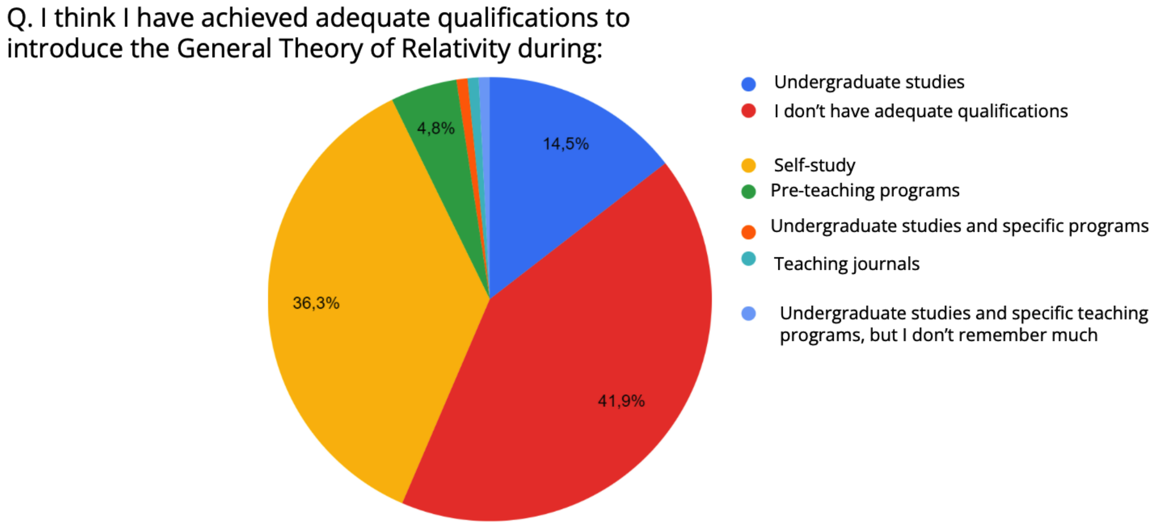

Figure 7. The great majority of teachers says that they do not feel qualified to teach General Relativity or that they achieved an adequate qualification thanks to self-study: this suggests the relevance of this type of training programmes.

In the first part of the training session, an interactive web-based platform was presented to introduce Relativity [20]. It is inspired by Einstein and Infeld's book "Evolution of Physics" [21]. It provides a step-by-step conceptual path which, starting from Galileo and Newton, introduces the basic ideas of General Relativity.

The laboratory part focused on using online maps to evaluate the impact of the relativistic corrections to GPS accuracy. In doing so, we took inspiration from the Einstein-First project [22], an international research collaboration which aims to introduce the fundamental ideas of modern physics at every level of education.

In figure 8 you can see an example of the exercise that can be assigned to students, where they are asked to determine the destination which would be indicated by the GPS instead of the desired one, if one or more relativistic corrections were neglected. This is very important to understand the relevance of Einstein's theory in everyday life. The idea is very simple: we must go from the yellow starting point to the red destination; but, if we neglect the relativistic correction, the accuracy greatly decreases, and it is impossible to know where the true destination is.

4. Conclusions

This course laid the foundation for a series of contacts and relationships among teachers from different schools, which was very important for novice teachers. In addition, it gave the possibility to share knowledge about specific technologies and software, as well as experiences on different projects. The activities illustrated to the teachers can be applied in different contexts and can be included in civic education courses and, in the case of secondary school, in dual training (learning and working).

Satisfaction questionnaires testify that the collaboration worked, and teachers were interested in the tools and topics which we proposed, and in the project structure. This project is experimental, and we are going to improve it. Given the reform of teacher recruitment we have to plan training courses for novice teachers and to reschedule the in-service training. Thus, the project has been a first step to renew teachers' training. Participants suggested some topics and tools for future meetings, and they asked for further deepening of some of the topics, above all those related to new technologies. The implementation of emerging technologies in educational practice has intrinsic difficulties given their rapid changes, this is why continuous training for teachers is always necessary.

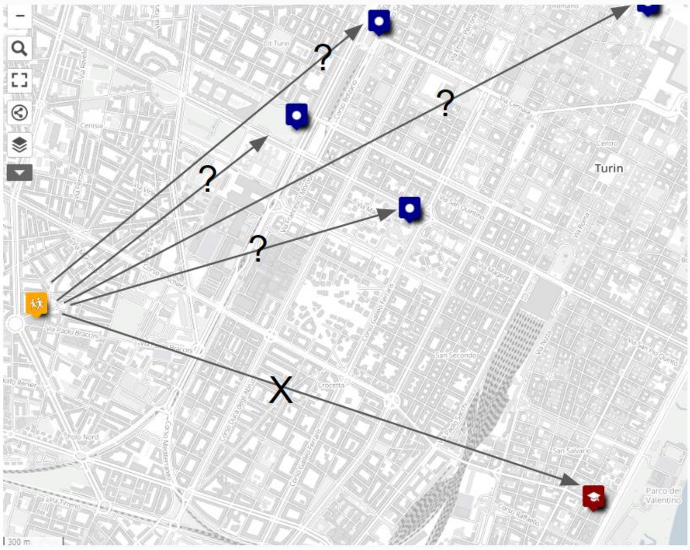

Figure 8. When relativistic corrections are turned off, the accuracy of GPS greatly decreases so, the knowledge of the position of our destination (in red in the figure) is poor, and we risk ending up in unwanted places (in blue in the figure)

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