# Physics Education Research

Speaker: Marta Carli (Researcher)

Group: Ornella Pantano, Lucia Gabelli, Stefania Lippiello, Eva Elisa Dryden Silva
+ new post-doc from July 2024

# What is Physics Education Research?

Research GRoup on Astronomy and Physics Education

PER investigates the problems of **teaching and learning specific disciplinary content** at **all instructional levels** and **settings** (classroom, lab, …)

Research

Investigation of students' **understanding**
*What are students' difficulties and resources?*
*How do we assess them?*

Gender/inclusion

Interdisciplinarity

Teacher preparation

Develop the **curriculum and activities** based on **evidence**
*What should students learn?*
*What teaching strategies are more appropriate?*
*How do we develop effective teaching materials?*

Practice

# What is Physics Education Research?

Research GRoup on Astronomy and Physics Education

- **Carried out by physicists** (expertise in the subject <u>needed</u>!)

- Both **theoretical and experimental**

- **Methodologies** borrowed from a variety of disciplines/fields
  - Quantitative methods: i.e. statistical methods (test theory, factor analysis, analysis of variance, structural equation modeling, …)
  - Qualitative methods: e.g. content analysis, thematic coding of interviews, participant observation, analysis of artifacts

- A variety of **tools and settings**, e.g. surveys, standardized tests, interviews and focus groups, classroom observations, …

- **Interactions** with different stakeholders and communities (students, teachers, curriculum developers, researchers from different fields)

# What is Physics Education Research?

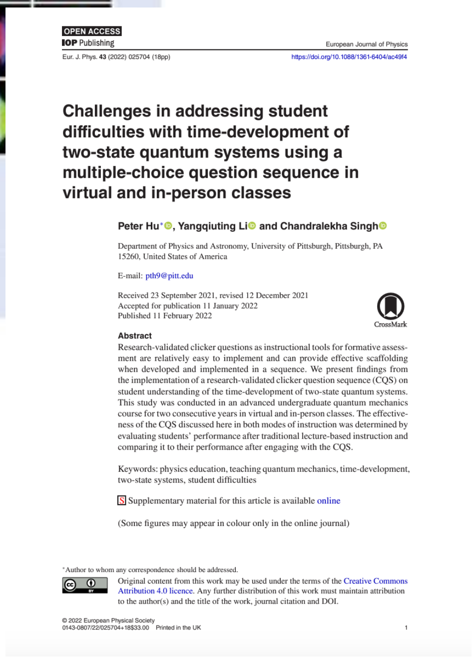

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH

Highlights | Recent | Accepted | Collections | Authors | Referees | Search | Press | About | Editorial Team

## Implementation and goals of quantum optics experiments in undergraduate instructional labs

Victoria Borish and H. J. Lewandowski

Phys. Rev. Phys. Educ. Res. **19**, 010117 (2023) – Published 3 March 2023



OPEN ACCESS
IOP Publishing European Journal of Physics
Eur. J. Phys. 43 (2022) 025704 (18pp) https://doi.org/10.1088/1361-6404/ac4f4

## Challenges in addressing student difficulties with time-development of two-state quantum systems using a multiple-choice question sequence in virtual and in-person classes

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**Abstract**
Research-validated clicker questions as instructional tools for formative assessment are relatively easy to implement and can provide effective scaffolding when developed and implemented in a sequence. We present findings from the implementation of a research-validated clicker question sequence (CQS) on student understanding of the time-development of two-state quantum systems. This study was conducted in an advanced undergraduate quantum mechanics course for two consecutive years in virtual and in-person classes. The effectiveness of the CQS discussed here in both modes of instruction was determined by evaluating students' performance after traditional lecture-based instruction and comparing it to their performance after engaging with the CQS.

Keywords: physics education, teaching quantum mechanics, time-development, two-state systems, student difficulties

Supplementary material for this article is available online

(Some figures may appear in colour only in the online journal)

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## A teaching-learning sequence about climate change: From theory to practice[a]

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(Received 30 November 2022; accepted 14 July 2023)

We describe a collection of relatively simple experiments and laboratory demonstrations devoted to the physics of Earth's energy balance. Many of the experiments also address fundamental aspects of physics at the undergraduate level. Results of classroom testing of this sequence of activities are presented and discussed. © *2023 Published under an exclusive license by American Association of Physics Teachers.* https://doi.org/10.1119/5.0137089

### I. INTRODUCTION

Climate change, a phenomenon with no political or geographical boundaries, is one of the most important issues facing our world. It is part of the role of science to relate issues concerning global warming to the physics and chemistry of the atmosphere using formal theoretical and experimental tools and protocols. At the university level, through carefully structured laboratory investigations, students can study the physics of the atmosphere, learn methods of experimental and theoretical investigation, and understand the ethical commitment of the scientific community to address issues of importance to humanity and the planet.[1,2]

We present here an experiment-based teaching-learning sequence (TLS), suitable for undergraduate and masters students, mainly devoted to the physical basis of the greenhouse effect (GHE), leading to the development of a simple but effective model for the Earth's climate[3] that is within reach of students and allows qualitative predictions of the radiative steady-state average temperature of the Earth-atmosphere system receiving radiation from the Sun and understanding of the effects of the increase in greenhouse gases in the atmosphere. Feedback effects can be included as well. The need for a TLS dedicated to this specific topic stems from the fact that the GHE is difficult to place in traditional physics and science curricula because it requires concepts from several traditionally distinct areas in physics. The TLS includes interesting phenomena in optics, thermodynamics, and radiative transfer that help students integrate knowledge and see physics as a unitary discipline.

The paper is organized as follows: In Sec. II, we outline the methodology we adopted in developing and improving the TLS. Then, in Sec. III, we describe the model we construct in the TLS. In Sec. IV, we provide a short description of the context of the experiments and the methods for data collection, and in Sec. V, we discuss the difficulties and misconceptions of students, considering both the literature and the results of our pre-tests. In Sec. VI, we provide a detailed description of the various experimental activities. In Sec. VII, we describe the results of the assessments we have conducted on the students who completed the sequence. Section VIII is devoted to our conclusions.

### II. FRAMEWORK

#### A. Design principles

Designing a TLS for a complex phenomenon like the GHE requires integrating concepts from different areas of physics. The sequence must also be accessible, appealing, and useful for students with diverse backgrounds, including future teachers of many disciplines: physics, mathematics, chemistry, Earth, and life sciences. Finally, a basic goal is to provide a progressive construction of a model of the GHE with increasing complexity.

These considerations make it almost essential to build the teaching-learning sequence around a series of experimental activities. Constructing concepts through experimental activities keeps all students engaged, even those who may already have a reasonable working knowledge of the topic at hand, through laboratory activities that may still be novel to them and help consolidate their knowledge. On the other hand, for students who are novices, experiments constitute a meaningful context for laying the foundations of a progressive construction of concepts.

#### B. Design of experiments

In designing the experiments, we were guided by the AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum[4] which emphasizes designing experiments; modeling, analyzing, and visualizing data; and communicating physics. We tried to implement structured inquiry-based lab activities[5] in which the teacher specifies the problem and the procedure to be followed, but the outcome of the experiment is not known in advance, and some decision-making space is left for students during the investigation. We frequently (for example, in the activity on thermal equilibrium of different bodies under radiation or the one on the Beer–Lambert absorbance law) use the Predict-Observe-Explain (POE) strategy as the base of the structured inquiry approach: The inquiry research question is the one which is posed to students in the "predict" phase, and subsequently, the student is guided to perform the experimental activity, collect data and analyze the results, compare them to their initial prediction, and possibly develop a new model.



# PER @UniPD: research topics

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- **Development of scientific practices** in instructional laboratories
  - High school
  - **NEW! Undergraduate**
- **Mathematics in physics education** at the boundary between high school and university
- **NEW! Quantum physics in High School**

(context: «Department of Excellence» project *Quantum Frontiers*)

Equity, gender, inclusion

Teachers' professional development

# PER @UniPD: examples

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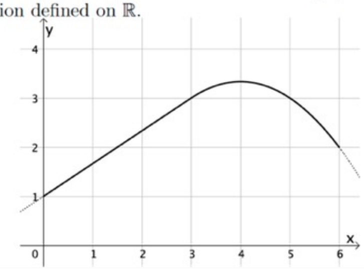
PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **16,** 010111 (2020)

## Testing students ability to use derivatives, integrals, and vectors in a purely mathematical context and in a physical context

Marta Carli,[1,†] Stefania Lippiello,[2] Ornella Pantano,[1]
Mario Perona,[3] and Giuseppe Tormen[1,*]

**Item 3M.** The figure below shows the graph of $f$, a function defined on $\mathbb{R}$.




Let $f'$ be the first derivative of $f$. What is the value of $f'(3)$?

(A) 2/3

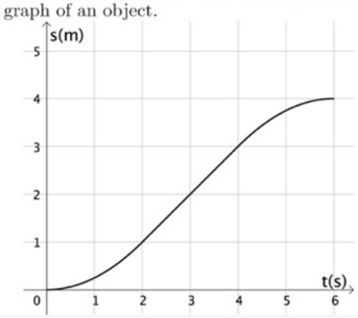
(B) 3

(C) 3/2

(D) 1

(E) 1/3

**Item 3P.** The figure below shows the position-versus-time graph of an object.




What is the object's velocity at t=3s?

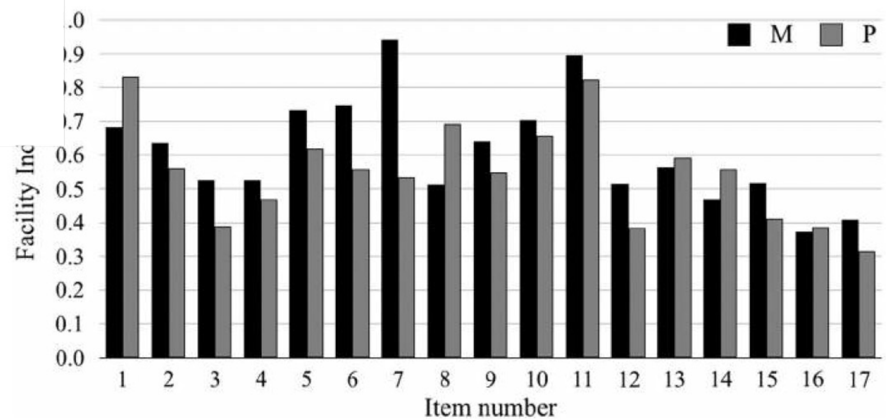
(A) 1.0 m/s

(B) 2.0 m/s

(C) 1.5 m/s

(D) 0.67 m/s

(E) 0.5 m/s




- Math/Phys, university level
- Quantitative research (survey, 1200+ students)
- Simple statistics + classical test theory

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Research GRoup on Astronomy and Physics Education

PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **16,** 010111 (2020)

**Testing students ability to use derivatives, integrals, and vectors in a purely mathematical context and in a physical context**

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TABLE III. Point-biserial coefficients ($r_{pb}$), discrimination indices ($DI_{27\%}$) and percentage of students who selected each of the five options for each item in the context of physics.[a]

| Item | $r_{pb}$ | $DI_{27\%}$ | A | B | C | D | E | Omit |
|---|---|---|---|---|---|---|---|---|
| 1P | 0.39 | 0.35 | 83 | 5 | 2 | 2 | 3 | 5 |
| 2P | 0.64 | 0.81 | 56 | 17 | 10 | 9 | 4 | 3 |
| 3P | 0.63 | 0.78 | 39 | 5 | 6 | 45 | 2 | 3 |
| 4P | 0.44 | 0.56 | 47 | 8 | 3 | 12 | 26 | 4 |
| 5P | 0.59 | 0.74 | 62 | 22 | 2 | 1 | 10 | 3 |
| 6P | 0.59 | 0.75 | 56 | 17 | 12 | 2 | 10 | 3 |
| 7P | 0.56 | 0.73 | 53 | 14 | 5 | 8 | 13 | 7 |
| 8P | 0.56 | 0.64 | 69 | 5 | 3 | 13 | 6 | 4 |
| 9P | 0.55 | 0.70 | 55 | 17 | 4 | 15 | 3 | 5 |
| 10P | 0.55 | 0.66 | 66 | 16 | 4 | 4 | 6 | 5 |
| 11P | 0.48 | 0.43 | 83 | 3 | 3 | 2 | 2 | 7 |
| 12P | 0.48 | 0.57 | 39 | 20 | 15 | 13 | 2 | 11 |
| 13P | 0.50 | 0.59 | 59 | 10 | 4 | 8 | 9 | 10 |
| 14P | 0.54 | 0.68 | 56 | 9 | 6 | 4 | 10 | 14 |
| 15P | 0.51 | 0.62 | 41 | 22 | 24 | 2 | 2 | 9 |
| 16P | 0.53 | 0.65 | 39 | 7 | 11 | 12 | 12 | 19 |
| 17P | 0.42 | 0.50 | 32 | 5 | 10 | 13 | 14 | 26 |

[a]Option A is the correct one for all the items; the order of the options was randomized in the version administered to the students. The value in the A column normalized to 1 gives the facility index.

TABLE V. Facility index (FI) differences and phi coefficients (Φ) for pairs of parallel items in the context of mathematics (M) and in the context of physics (P). FI differences larger than 10% and Φ values smaller than 0.30 are labeled with an asterisk, and the item pairs having at least one of the two values above threshold are marked in bold.

| Item pair | FI(M) | FI(P) | FI difference (M-P) | Φ |
|---|---|---|---|---|
| **1** | 0.68 | 0.83 | −0.15* | 0.28* |
| 2 | 0.64 | 0.56 | +0.08 | 0.49 |
| **3** | 0.52 | 0.39 | +0.13* | 0.36 |
| **4** | 0.53 | 0.47 | +0.06 | 0.20* |
| **5** | 0.73 | 0.62 | +0.11* | 0.35 |
| **6** | 0.75 | 0.56 | +0.19* | 0.26* |
| **7** | 0.94 | 0.53 | +0.41* | 0.14* |
| **8** | 0.51 | 0.69 | −0.18* | 0.28* |
| 9 | 0.64 | 0.55 | +0.09 | 0.42 |
| 10 | 0.70 | 0.66 | +0.04 | 0.46 |
| **11** | 0.89 | 0.83 | +0.06 | 0.27* |
| **12** | 0.51 | 0.39 | +0.12* | 0.35 |
| 13 | 0.57 | 0.59 | −0.02 | 0.44 |
| 14 | 0.47 | 0.56 | −0.09 | 0.35 |
| **15** | 0.52 | 0.41 | +0.11* | 0.35 |
| 16 | 0.37 | 0.39 | −0.02 | 0.36 |
| 17 | 0.41 | 0.32 | +0.09 | 0.35 |

In order to highlight the role that contextualization might have played in the students' framing of these two items, we report an excerpt from one of the pilot interviews. Just before this conversation, the student had tried to solve item 15M, and he had calculated the sum of the two vectors instead of their difference. Then he was asked to solve item 15P.

*Student: It is about circular motion. We have centripetal acceleration. Centripetal acceleration is… v square over r… it points to the center… [looks puzzled]*
*Interviewer: What are you thinking about?*
*S: None of these answers is correct, because it [acceleration] points to the center, so it should be like this [draws a vector pointing to the center, starting at point 1] here, and like this [draws a vector pointing to the center, starting at point 2] here. The Moon moves on a circle, but its speed is constant. This is constant circular motion.*
*I: Ok. If I told you the correct answer was there, what would you say?*
*S: Well, if I must choose among these ones, I'd say zero [distractor C], since they [the two vectors] have the same magnitude. But there is centripetal acceleration, unless they are asking something different.*

The student did not immediately frame item 15P as a problem about vector difference. Instead, he started recalling miscellaneous facts and formulas about circular motion, which, however, did not cue him towards the correct answer. When invited to select one of the given options, the student chose option C (corresponding to the magnitude

# PER @UniPD: examples

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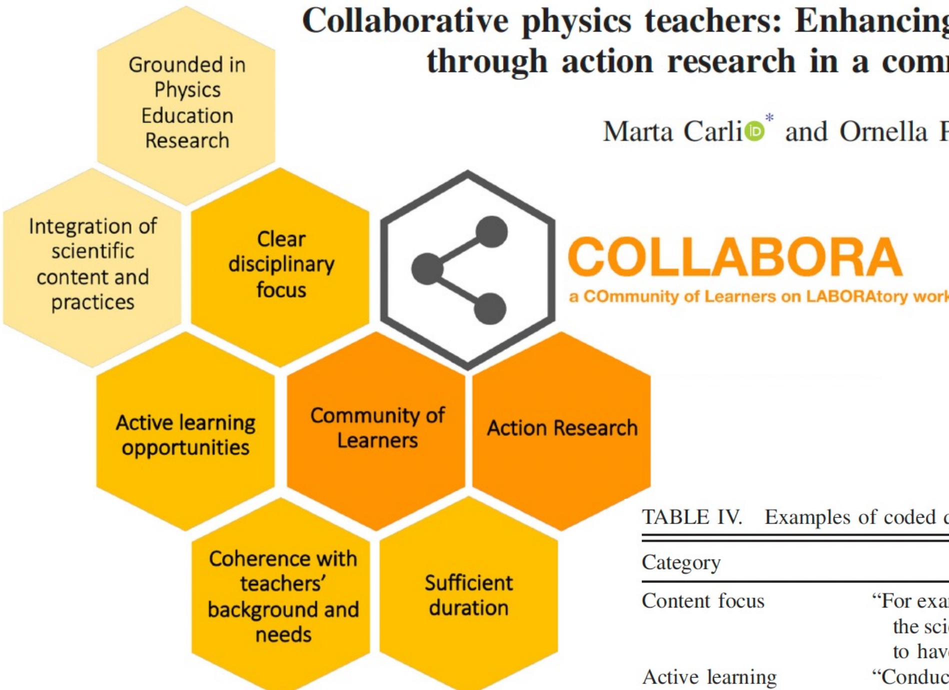
PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **19**, 020162 (2023)

## Collaborative physics teachers: Enhancing the use of the laboratory through action research in a community of learners

Marta Carli* and Ornella Pantano




- Labs, high-school level, teacher PD
- Qualitative research (11 teachers, interviews + focus groups)
- Thematic coding, multiple case studies

TABLE IV. Examples of coded quotes for each of the features considered in RQ1.

| Category | Example of quote |
|---|---|
| Content focus | "For example, one of the flaws of my preservice training was that pedagogy courses had nothing to do with the science part. As a result, we sometimes found them a bit distant from our needs. It is far more beneficial to have courses focused on physics education." |
| Active learning | "Conducting experiments firsthand, while drawing upon diverse expertise and possibly different areas of focus, motivated us and likely gave us a better understanding of how students might perceive a particular activity." |
| Coherence | "I was really thirsting for it. Ever since I started teaching, one thing I lacked was a little bit of research. So, it gave me a sense of relief to discover that I'm not alone and that there is somebody out there working on this." |
| Sufficient duration | "It was good that we could experiment during the course, reflect, and try to apply something in the classroom. And if something went wrong, you could catch up the following month." |
| Community of learners | "It means a lot, that we are together. We all share more or less the same problems and we all try to do our best. Personally, this community is important as it serves as a reference point for me. I feel like I belong here, I feel good here." |
| Action research | "I was tired of doing things for pretend. This time, I had a classroom where I could experiment, I could try to do it concretely." |

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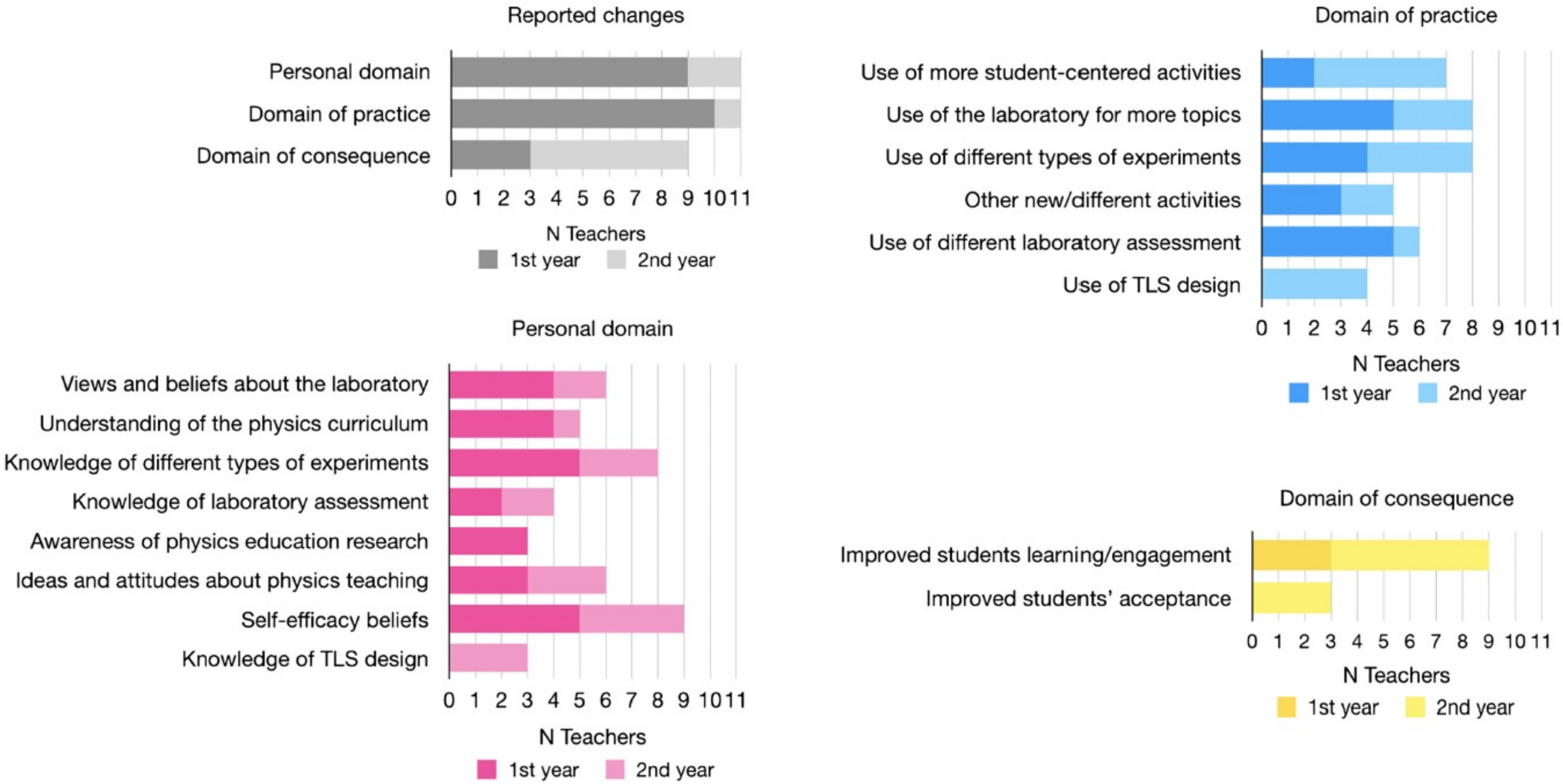

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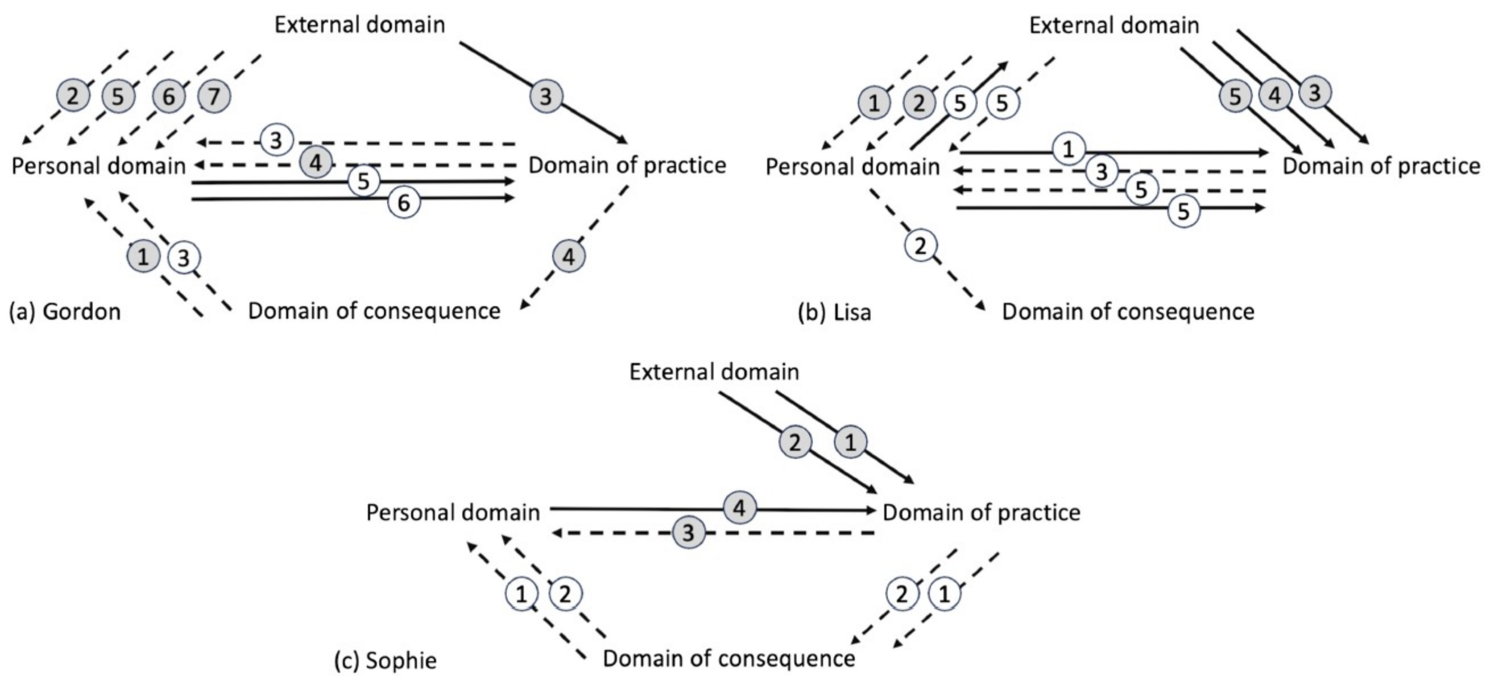


FIG. 9. Participants' trajectories across the different domains of change, mediated by the processes of enactment (solid lines) and reflection (dashed lines): (a) Gordon, (b) Lisa, (c) Sophie. Numbers refer to the quotes reported in the tables for each participant. The gray color marks the first move for each instance.

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PAPER
Phys. Educ. 56 (2021) 025010 (9pp) iopscience.org/ped

## Teaching optics as inquiry under lockdown: how we transformed a teaching-learning sequence from face-to-face to distance teaching

Marta Carli[1], Maria Rosa Fontolan[2] and Ornella Pantano[1]

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[2] Liceo Scientifico Statale 'P. Paleocapa', Rovigo, Italy

E-mail: marta.carli.1@unipd.it

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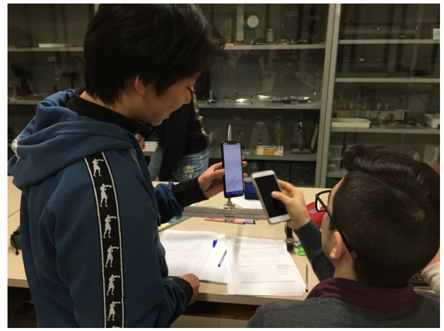


- Labs, high-school level
- Mixed methods research
- Intervention + observations + tests



**Table 1.** The design matrix of the teaching-learning sequence.

Core ideas and scientific practices from *A framework for K-12 science education* [3]

**Core idea:** Waves and their applications
**Scientific practices:** Developing and using models; Planning and carrying out investigations; Using mathematics and computational thinking; Analyzing and interpreting data.

| **Understandings** | **Essential questions** |
|---|---|
| (U1) The ray model explains some light phenomena (shadows, reflection, refraction), but not all of them. Some phenomena, such as the patterns we observe when light passes through a small aperture, are explained by modelling light as a wave. (U2) Since light is a wave, it is characterized by a velocity, a frequency and a wavelength, related through the wave equation. Light intensity is related to the amplitude of the wave, while colour is related to the wavelength of light. Interference and diffraction are observed as a consequence of the interaction of light with itself or with objects. (U3) Interference and diffraction of light explain some everyday phenomena such as the colours of bubbles or of a CD and can be used in different technological applications. | (EQ1) What models can we use to explain light phenomena and what is their validity? (EQ2) What are the consequences of modelling light as a wave? (In particular, what physical quantities are used to describe light and how do we interpret the features of light related to these quantities? What phenomenology do we expect to observe?) (EQ3) What are some everyday phenomena where we observe the wave nature of light? |

**Assessment**

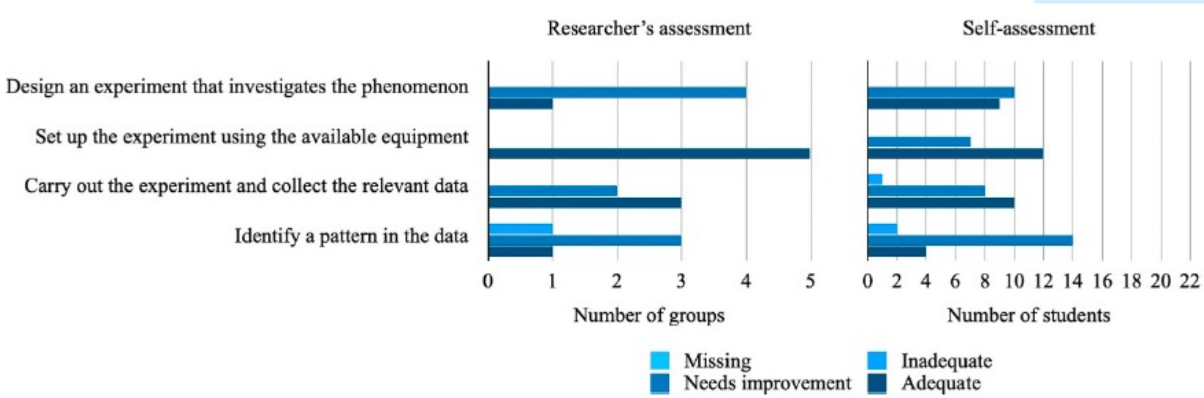
Application experiment'—Measuring the thickness of a hair. Assessed

ssess students' knowledge and abilities.
nt rubric filled in by the students.

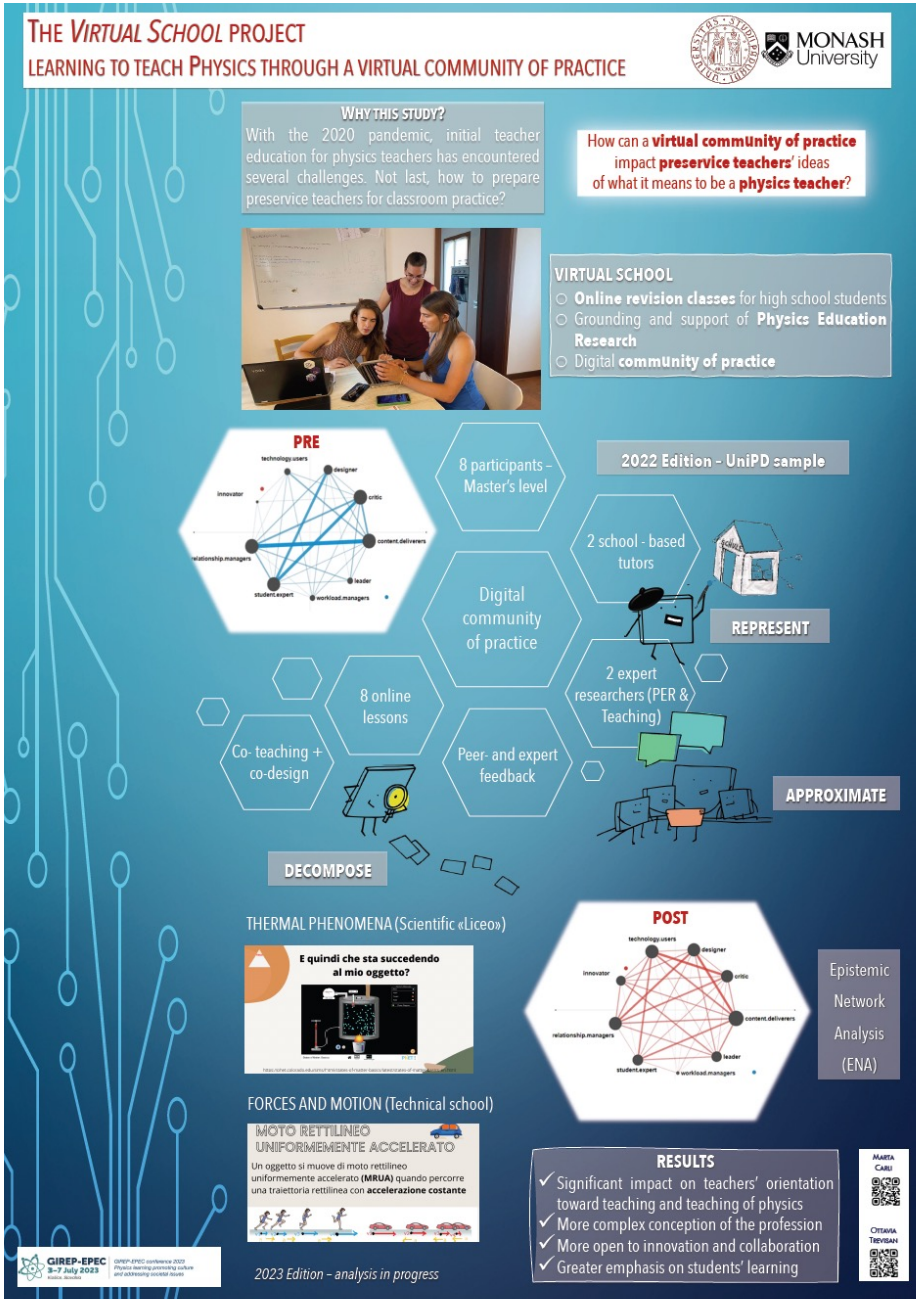
11] model)

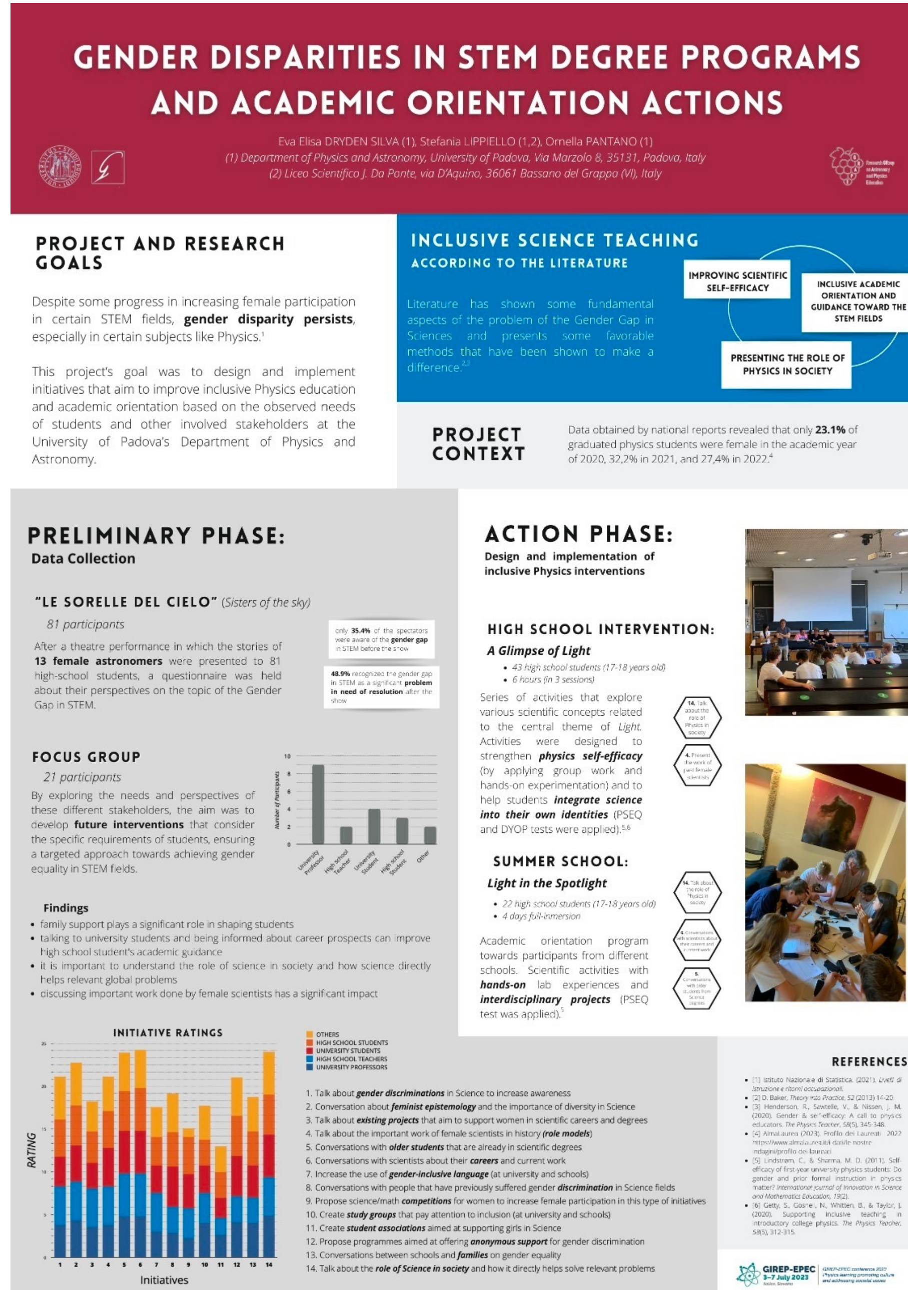
the students observe different optical phenomena that can be explained with ray
predict what happens when a laser beam passes through a small slit, they observe
the fact that they cannot explain the observed pattern using the ray model.
riment': the students design and perform an experiment to investigate the phe-
ffraction and collect data in order to identify patterns and trends.
l conceptualization: the students share and compare their results, which are then
del; the interference and diffraction patterns are interpreted using wave superpos-
the conditions for interference and the formulas describing the positions of the
Textbook exercises are assigned as homework.
nent': the students are asked to set up and carry out an experiment to find the

udents and the teacher engage in a discussion on the use of different models for



- Initial teacher training




- Gender & inclusion in Physics

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Research GRoup on Astronomy and Physics Education

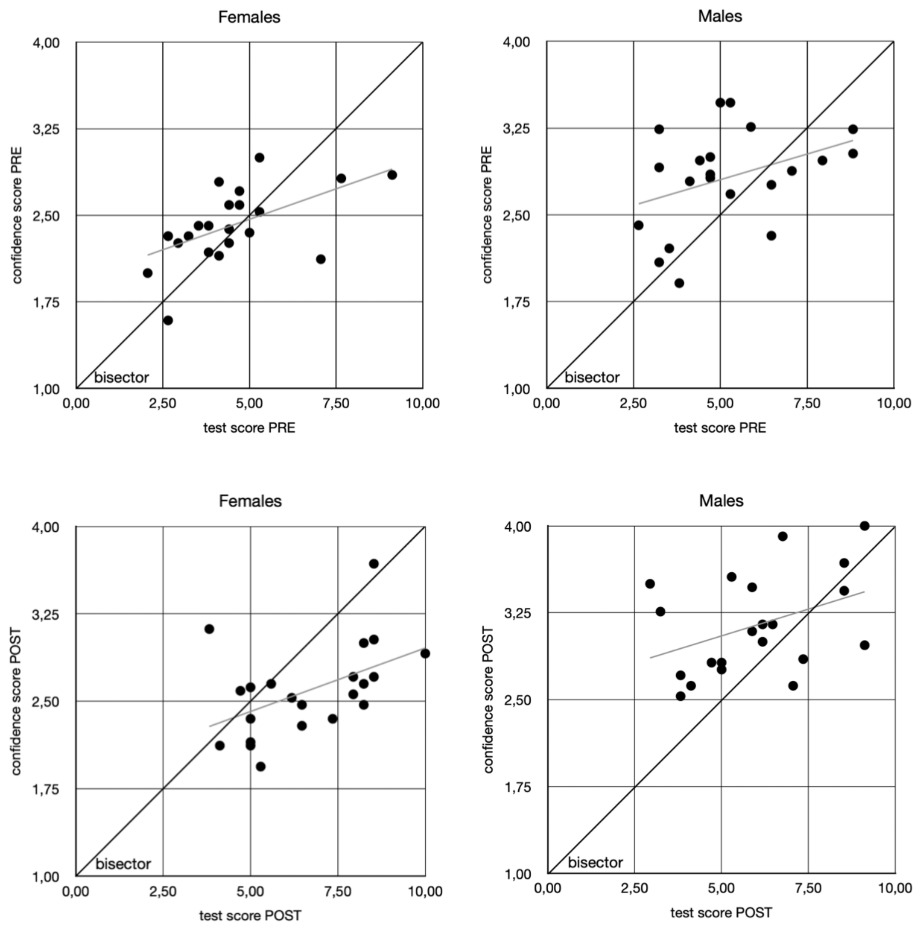
*International Journal of Science and Mathematics Education*

**Mathematisation skills for physics in secondary school: the relationship between performance and confidence and the role of gender**

S. Lippiello[a,b], M. Carli[a], O. Pantano[a]

Article in preparation

- Stefania Lippiello's PhD project



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**Teaching scientific practices in high school: a learning progression**

(L. Gabelli et al.)

Article in preparation

- Lucia Gabelli's PhD project

| Scientific practices | first year | second year |
|---|---|---|
| A. Asking questions and defining problems | 08 Dynamometer<br>02 Range and sensitivity of scales | 19 Mechanical waves |
| B. Developing and Using models | 05 Vector sum<br>10 Motion in the plane | 22 Circuits |
| C. Planning and carrying out investigations | 06 What the pendulum period depends on | 15 The second principle of dynamics<br>21 The fundamental law of thermology |
| D. Analysing and interpreting data | 01 Causes of pendulum error<br>11 Linear motion | 23 Ohm's first law |
| E. Using mathematics and computational thinking | 04 Relationship between volume and mass of objects<br>13 Free fall | 18 Energy |
| F. Constructing explanations and designing solutions | 03 Improving the period of a pendulum<br>12 Uniform linear motion | 17 Circular motion |
| G. Engaging in argument from evidence | 07 Weight force<br>14 Uniformly accelerated motion | 24 Resistance of a conductor |
| H. Obtaining, Evaluating, and communicating Information | 09 Dynamic friction | 16 Seat belts<br>20 Sound |

# Current MSc theses

- Improving the Test of Calculus and Vectors in Mathematics and Physics: an evidence-centered approach (Luca de Vidi)
- Students' attitudes about experimental physics at the University of Padua: a ground for innovation (Davide Caruso)
- Teaching quantum physics in secondary school: the teachers' perspective (Denis Cogo)

# PER @UniPD: examples

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Newest project/1

- Undergraduate labs
- Based on the ECLASS instrument

Data NOT from our research (data collection still ongoing)

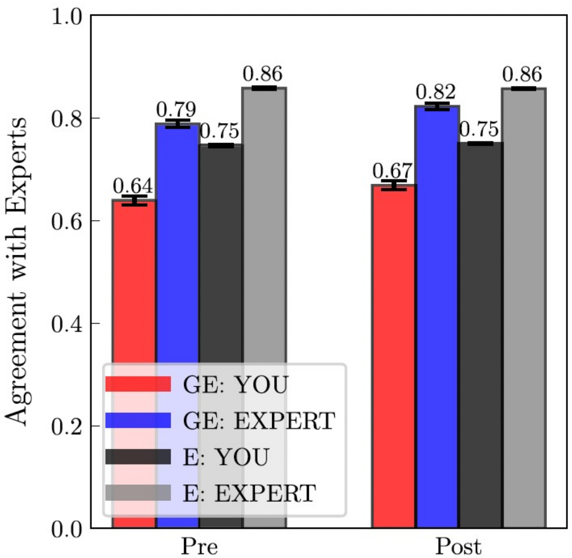
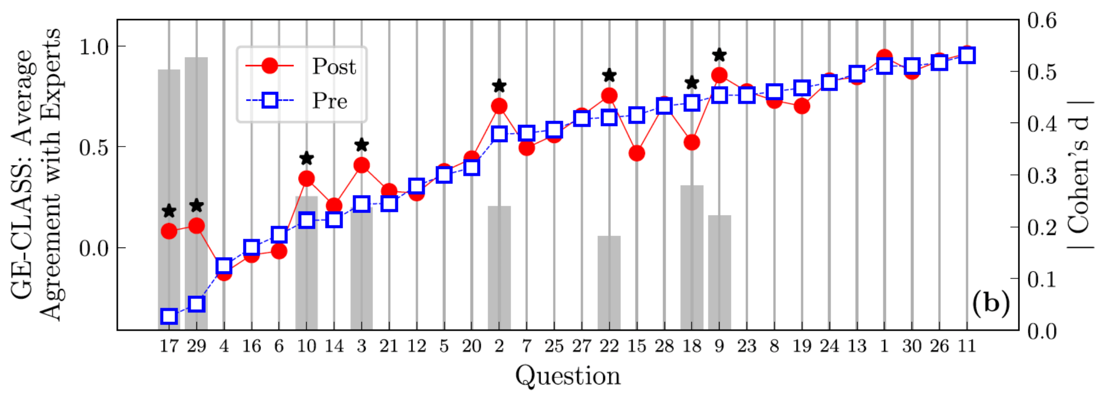



FIG. 1. Overall GE-CLASS agreement with experts for the pre- and post-tests. Perfect agreement with experts corresponds to one, zero means no agreement with experts. In red are the GE-CLASS results for YOU questions and in blue for the EXPERT questions. For comparison, E-CLASS results are indicated in the figure as well (in dark and light gray). The overall mean shown here averages over all students and all items on the survey. Error bars are standard deviations of the mean.

**When doing a physics experiment, I don't think much about sources of systematic error.**

| | | |
|---|---|---|
| Strongly Disagree 1 2 3 4 5 Strongly Agree | | |
| *What do YOU think when doing experiments for class?* | ○ ○ ○ ○ ○ | not answered |
| *What would experimental physicists say about their research?* | ○ ○ ○ ○ ○ | not answered |
| Unimportant 1 2 3 4 5 Very Important | | |
| *How important for earning a good grade in this class was **thinking about sources of systematic error?*** | ○ ○ ○ ○ ○ | not answered |

FIG 11. 1 A set of three examples questions around one key statement in the survey.



# PER @UniPD: examples

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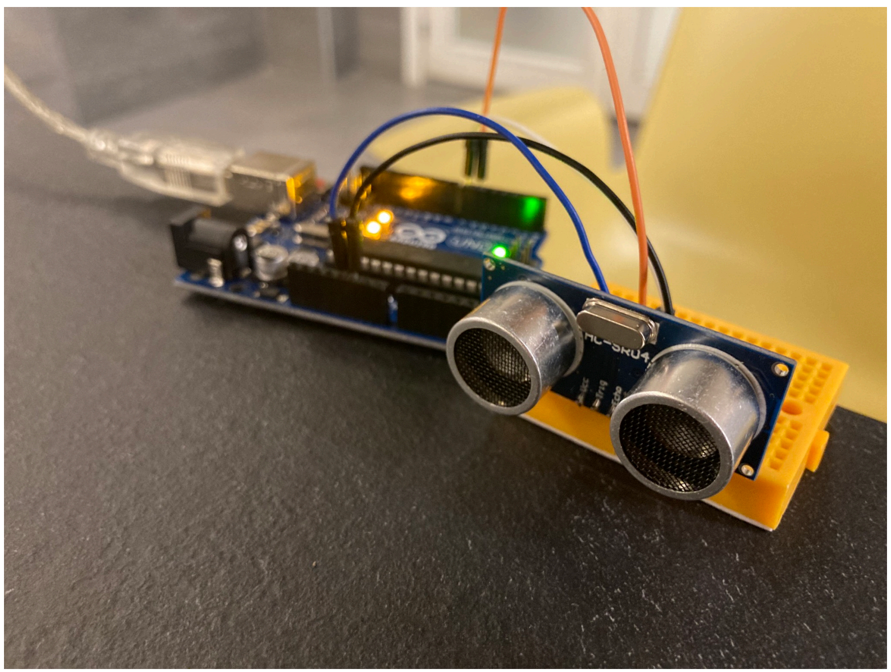
Newest project/2

- High school labs
- Use of Arduinos/smartphones in the lab
- PRIN2022 project




Adelante

Adopting Digitally-Enhanced LAboratories in a Network of TEachers

# Our group

Research GRoup on Astronomy and Physics Education

Ornella Pantano

Marta Carli

Lucia Gabelli

Stefania Lippiello

Eva Elisa Dryden Silva

Current Master's students:

- Davide Caruso
- Luca De Vidi
- Denis Cogo

**NEW!** Eugenio Tufino
Post-doc (starting July24)

# Contact map

Research GRoup on Astronomy and Physics Education

# Contacts

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Questions are welcome!