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Design for Physics

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Abstract. Design for Physics is a joint project between a physics department and a design institute, aiming at engaging students who feel uncomfortable with scientific disciplines in the exploration of science. Students at IED were asked to design, produce and test low-cost, easy-to-build apparatus for physics experiments, intended for use in schools.

This paper presents the project as a case study, focusing on its structure, implementation, and outcomes. We report qualitative observations of the participating design students, acknowledging the exploratory nature of this investigation and the limitations due to participant selection based on availability rather than representativeness. We also gathered feedback from a group of physics teachers who tested the prototypes. The initiative, although limited in scope, highlights potential ways to bridge design and science education.

The project was honoured with inclusion in ADI's (Associazione per il Disegno Industriale) Design Index 2024, the esteemed annual collection of the best designs produced in Italy, and received the Excellence in Design in Lazio prize.

1. Introduction

The Design for Physics project began as a transdisciplinary collaboration between a scientific department of a public university (Sapienza Università di Roma) and a private higher education institution (IED), with the shared belief that such collaboration could foster innovative educational experiences at the intersection of science and design.

This paper presents a case study focused on the development of a production design course held at IED in the academic year 2022/23 by one of us (Mauro Del Santo, MDS) under the coordination of Gianfranco Bombaci (GB). The course aimed to introduce students to design tools (in particular CAD software), material properties, surface finishes, and aspects related to product aesthetics.

While aesthetics is traditionally undervalued in scientific practice, it can play a non-negligible role, particularly regarding the usability, clarity, and even the perceived reliability of scientific instruments. Although there is limited systematic research on this specific link, our professional experience suggests that instruments designed with care for visual appearance tend to exhibit greater robustness, fewer handling errors, and improved user interaction. For example, the discreet integration of mechanical fasteners can enhance stability, colour coding can reduce operational mistakes and facilitate maintenance, and orderly cable routing can prevent physical obstructions and, in some cases, reduce electromagnetic interference.

Beyond practical considerations, aesthetics can also have a motivational value, especially in the context of teaching laboratories, where students' curiosity, engagement, and desire to explore are essential for meaningful learning.

Interest in the relationship between aesthetics and science education has only recently begun to emerge. Notably, the 2019 ESERA conference included the symposium ”The Beauty and Pleasure of Understanding: Engaging With Contemporary Challenges Through Science Education”[1]. The proceedings, later published as a special issue of the Journal of Science Education[2], emphasise the role of aesthetic experience in promoting deeper learning, fostering memory retention, and supporting the construction of meaning in educational contexts. As several contributions in that volume suggest [3], research in this area remains at an early stage, yet preliminary findings indicate that the dimensions of beauty, aesthetics, and science learning are interconnected and worthy of further exploration.

In this project, we explored these ideas in a specific, situated context, without claiming broad generalisability. Our goal is to share preliminary insights and reflections, acknowledging the limitations of this case study, particularly regarding participant selection, which was based on availability rather than representativeness.

2. Description of the activities

The course on product design in which we included the project was offered by IED to students at its Rome branch. As a rule, the course has the nature of a workshop in which students are challenged to make a product. The course gradually provides all the necessary skills to go from a design in principle to the finished product.

We agreed to focusing on the design of instrumentation for an educational science laboratory. Also because, despite the importance of laboratory activity highlighted in a recent volume [4] collecting the most significant contributions to GIREP conferences on the subject, scientific practice is still too undervalued in physics teaching. One of the reasons given for the lack of attention paid to the laboratory by teachers is, in addition to lack of time, the cost of equipment. With this project, we aimed to explore the possibility of making products affordable for every school. In fact, the final cost of the prototypes allows schools to procure not one, but several, enabling students to engage directly with the experiments rather than merely observing the teacher or lab technician, thus promoting a more active learning experience.

All instruments had to be designed to be used in conjunction with a smartphone with the phyphox [5] app installed to perform the required measurements. To this end, one of us (Giovanni Organtini, GO) gave two preparatory lectures on the activities that are normally conducted in a physics teaching laboratory, illustrating a few solutions available on the market and highlighting their merits and flaws.

During the next few weeks, the students learnt how to design and build prototypes until they came up with a first non-functioning version of the products, typically made of cardboard or polystyrene. These dummies serve to verify from life the size and final appearance of the objects to be made, that the assembly procedures are correct and easy to perform, and that there are no obstacles to their operation.

By assembling these prototypes, students become aware of possible difficulties, and can correct their designs to overcome them.

During this phase, GO was present and could take part in the prototype evaluation stages. On this occasion, the students received prescriptions on what and how to modify, as well as advice on possible ways to improve the user experience from the students who were supposed to use the tools in the first place.

The construction plans were therefore revised in the light of the experience gained on the first prototypes, and the final designs were drawn up.

MDS explained, together with GB, some design principles regarding the choice of materials and finishes, as well as the final appearance of the prototypes. Together, they chose to give the tools a common identity by giving them a look similar to the Italian design products of the

(a) free fall device (b) pendulum

Figure 1: the devices for studying free fall and the pendulum.

1960s, characterised by simple geometric shapes and bright colours [6]. Every detail has been taken care of: from the choice of the most appropriate bolts to the use of "chalky" finish paints.

In addition to the purely technical aspects, particular care was taken in the choice of materials and manufacturing techniques, so that the instruments would be particularly inexpensive (especially when compared to the typical cost of instruments normally used in these contexts), easy to build even by oneself, and environmentally sustainable.

The result was a set of visually appealing instruments, designed to be both functional for high school experiments and evocative of high-quality design objects.

Prior to production, GO had the opportunity to see the designs to verify that they met the requirements, then the parts were cut using a laser cutter (the tools are mainly made of 6 mm beech plywood). The instruments were then assembled and painted, before being inspected again to verify their expected function.

3. The instruments

The best designs were selected and made available throughout the Sapienza physics department website [7]. The drawings are distributed under a CC BY-NC-ND 4.0 DEED licence [8], which allows anyone to produce the tools. If you have a laser cutter of sufficient size, the parts can be made in-house, otherwise they can be outsourced to a service outside the organisation. Below, we describe the instruments whose design was made public.

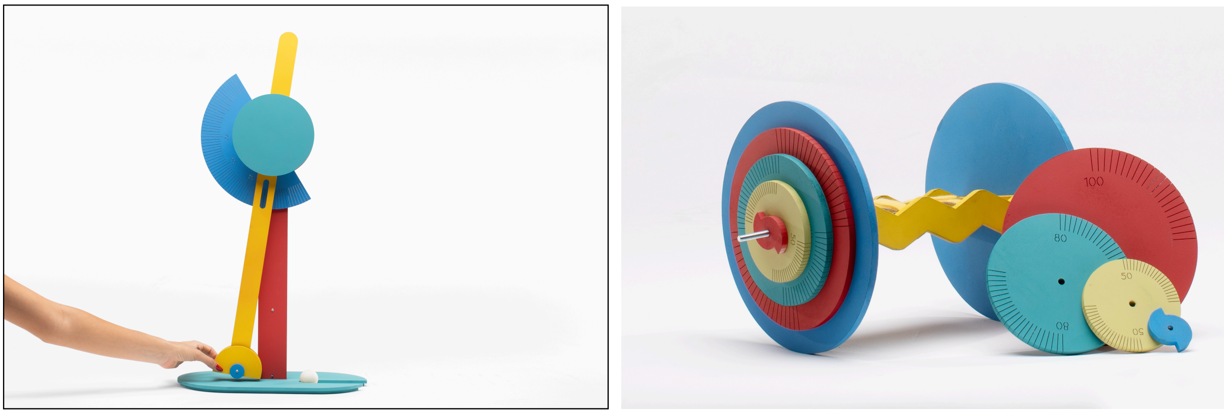
3.1. Free Fall

The study of free fall is made possible by a device consisting of a small cage suspended at a variable height (Fig. 1a). A ball can be placed in the cage. A small hammer hinged on the cage can then be raised and released so that, as it falls, it hits the cage at a point that allows a trapdoor to open underneath the ball, which then begins to fall.

The duration of the fall can be measured thanks to phyphox's acoustic stopwatch, sui start is triggered by a first noise of sufficient intensity (produced by the opening of the trapdoor) and a second strike produced by the ball hitting the ground.

3.2. Pendulum

The pendulum (Fig. 1b) makes it possible to study small oscillations. Using this instrument, one can study elementary dynamics, measure the acceleration of gravity, study friction forces, energy and the physics of rigid systems.



(a) launcher (b) dumbbell

Figure 2: the launcher and the dumbbell.

It consists of a universal housing for a smartphone, which can be attached at different distances from the axis around which the oscillations occur. The entire device can be fixed to the edge of a table. The period of oscillations can be measured exploiting either the accelerometer, or the gyroscope of the smartphone, as well as the magnetometer.

The friction is low enough to allow accurate measurements to be made over a relatively short period of time, but not entirely negligible, making it possible to study these forces and how the pendulum's energy is dissipated over time.

The structure is, at the same time, sufficiently light that it can be considered an almost ideal pendulum, but by making very precise measurements, the effects of not being so begin to become apparent.

A graduated protractor fixed near the axis makes it possible to study how the period changes as the amplitude of the oscillations varies.

It is advisable to use a fairly heavy ball to reduce the impact of air friction. The device can be used simply by placing it on a table, or by fixing it to the edge of a surface.

3.3. Launcher

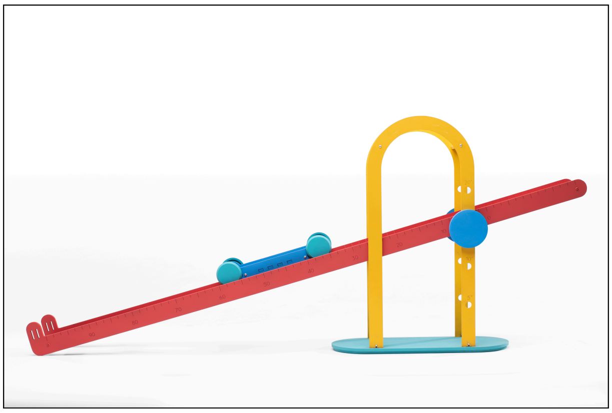
The launcher (Fig. 2a) is a device designed to launch an object (a ball) with a velocity component parallel to a chosen direction and of constant modulus.

It consists, in essence, of a ballistic pendulum: by lifting it to a certain height and dropping it, energy is transferred to a ball placed at its lowest point. The reproducibility of the energy transferred to the ball is ensured by the fact that the initial height is easily measured with a goniometer fixed to the pendulum's axis of rotation. The direction of the ball's motion is ensured by the fact that it is located at the end of a guide, which is short enough not to hinder its motion, but long enough to ensure that the ball will continue to move in the desired direction if it encounters no obstacles.

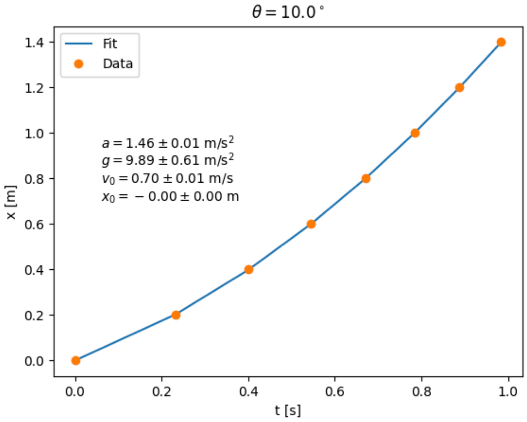
The motion of the ball can be studied with the phyphox acoustic stopwatch if you make it collide with something once set in motion, or simply by filming the experiment. In the latter case, one can use FizziQ [9], which, with its "video motion analysis" tool, allows one to trace the motion of the ball and collect data on its position as a function of time.

3.4. Dumbbell

The dumbbell (Fig. 2 b) is designed to study the dynamics of rotating systems. It is a housing for a smartphone, to which the latter is attached by means of elastic bands or Velcro strips.



(a) the inclined plane



(b) fit to data

Figure 3: a) the inclined plane; b) measurement of the position of the cart along the inclined plane as a function of time, using the magnetic sensor of a smartphone.

Two discs of equal diameter are placed on the short sides of the housing. The discs are easily interchangeable so that their diameter can be varied. The discs can also be mounted together so as to increase the mass for the same diameter. By letting the device roll along an inclined plane, for example, its angular velocity can be recorded as a function of time using the phyphox gyroscope.

3.5. Incline

The inclined plane (Fig. 3a) allows classic experiments with this device. In our case, small magnets are housed in the track, at regular distances from each other. The inclination can be varied by moving pegs in the appropriate slots.

The cart that can slide along the plane is designed to accommodate a smartphone. The study of the cart dynamics can therefore be carried out using both the accelerometer and the magnetometer, which records a very pronounced peak every time it passes over one of the magnets.

The wheels are designed in such a way as to offer practically negligible friction, comparable to that of carts produced by the most renowned manufacturers. The motion is smooth and operation is extremely simple. Fig. 3 b) shows a preliminary measurement done within minutes of the position of the cart as a function of time, measurement exploiting the magnetic signals.

4. Impact of the project

Although the number of IED students involved in the project was small, we still conducted an informal survey to see what the potential of this kind of activity was and whether it was worth extending it to larger numbers.

Students were asked to answer an anonymous questionnaire. Given the small number of people involved, the given answers could still lead to the identification of the student who gave them. For this reason, the students were free to answer or not.

It is important to note that the results of this investigation cannot be considered generalisable, given the limited number of participants, the self-selection bias, and the absence of a validated research instrument. Despite these limitations, the responses provided several interesting insights that, at the very least, could stimulate the community to pursue similar projects, with the aim of collecting statistically significant data and employing rigorously validated questionnaires.

We asked the students who wished to respond to offer their own free commentary illustrating the activity they had conducted and highlighting the moments that had impressed them most.

In each comment we found some confirmation of what we already know from research in physics didactics, and hints for new investigations.

The students who took part in the survey were all first-year students with a school curriculum hardly ever oriented towards technical or scientific subjects. In any case, their interest in physics was typically low.

Several complained that, during their school years, they were only taught physics from a theoretical point of view, without any related practical activities. Many only discovered this aspect through this project, and were enthusiastic about it.

In several cases, we observed how, a number of students, by the mere fact of having to design the devices, revisited and deepened their understanding of basic physical concepts such as energy and the effects of forces on motion, typically experienced in the first year of higher education.

In particular, the comment left by one of the students perfectly illustrates most of the problems encountered in teaching science subjects at school and calls us to do what we can to change this attitude of teachers: “This type of activity promotes the understanding of fundamental physical concepts as well as the development of analysis and problem-solving skills.The pendulum provides an excellent opportunity to explore concepts such as potential and kinetic energy, the period of oscillation and the effect of frictional forces on the amplitude of oscillations”. Any further comment is superfluous.

We also asked for the views of some teachers, who had the opportunity to try their hand with the tools produced in this project. The teachers were asked to look at the tools and see if and how they could use them in their teaching, without first explaining how they worked and without providing them with any documentary support. Only after using the tools for an afternoon were they given information on how to use them correctly. In many cases, however, the teachers could figure out for themselves how to use them. Only one out of 13 had difficulties in figuring out their usage.

We therefore asked them whether they felt they were doing enough laboratory work in their teaching practice and whether they felt that the availability of the tools proposed to them would change their habits. The result is illustrated in Figure 4.

5. Conclusion and outlook

The “Design for Physics” project consisted of instructing students on a product design course to design laboratory instruments for teaching physics.

Some of the instruments designed turned out to be particularly interesting. The products, illustrated in this article, can be easily produced with digital fabrication techniques and at low cost. The designs are available under a Creative Commons licence and can be customised, if required.

The development of the activities made it possible to explore the dimension of beauty and aesthetics in the teaching of physics: an aspect that is almost always neglected, but which may have educational potential, particularly in terms of increasing student engagement and fostering a more positive attitude towards science.

The experience carried out in this project is too limited from a statistical and methodological point of view to constitute a solid experimental basis for theoretical research in the field, but it does provide useful pointers for designing similar activities that are more coordinated and statistically relevant. With this paper, in addition to publicising the availability of the instrumentation in order to make it usable in many schools and universities, we would like to encourage interested colleagues to collaborate on this effort with the shared goal of developing

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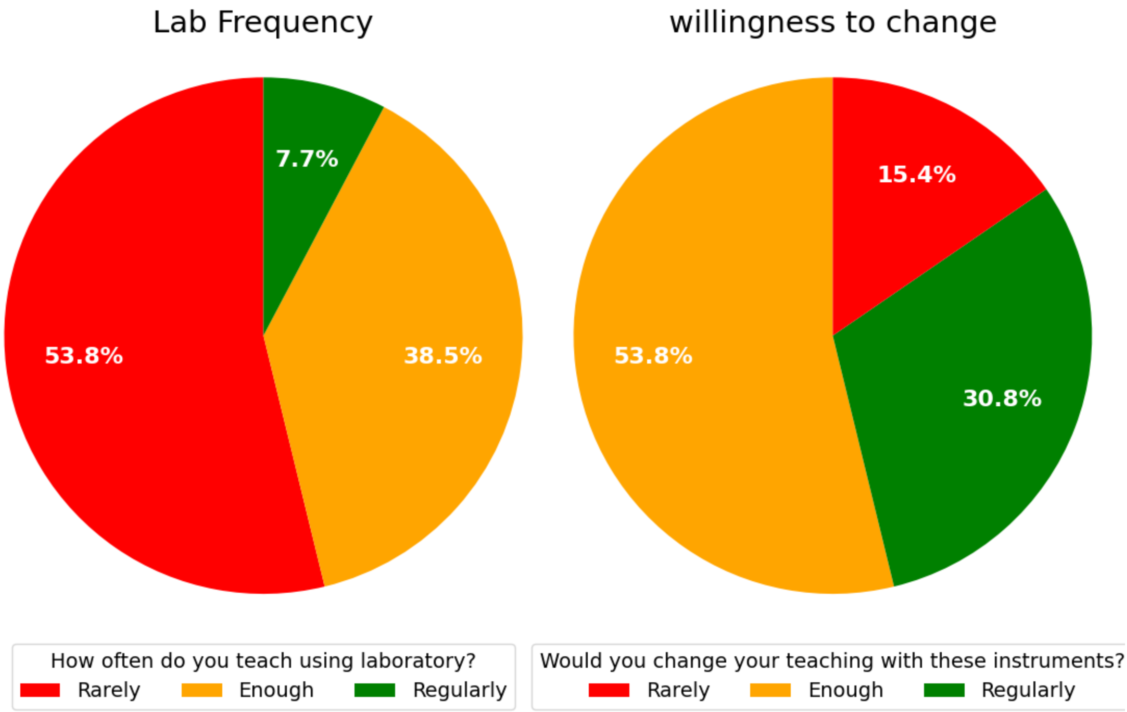

Figure 4: Response of the teachers.

both practical tools and rigorous research protocols to better assess the educational impact of such initiatives.

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