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Project ALEX: Teacher workshops on presenting physical concepts through improvised demonstrations and qualitative reasoning

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Summary. — We describe a physics pedagogy centered on everyday experience and qualitative reasoning that can be a useful supplement for students by linking more formal, separated parts of the traditional curriculum and provide a safety net for teachers in schools that do not have dedicated physics or chemical laboratories. We argue for an extension of practice, an enrichment of the presentation for both sides of the pedagogical transaction, not a radically new method or a replacement for the traditional Italian mode of instruction. This approach is even more relevant in these difficult times.

We advocate an approach that integrates within the methodology in which teachers in Italy are usually trained. Our project, A*strophysics* L*earning* EX*perience* and more ([1]), was presented to Liceo Scientifico Dante Alighieri (LSDA) in fall, 2018 and the first sessions were conducted in December of that year with additional workshops in May and December 2019. Participants included science and mathematics teachers from *licei* and *scuole medie* in the *provincia*. The work was spread over three days, each session involving *in situ* "encounter group"-style meetings in a laboratory setting involving about a dozen teachers, classroom lecturing and discussions involving up to twenty teachers, and sessions with students from LSDA in several classes, a few dozen each. A public talk and open discussion was included in each visit, also involving teachers from outside of physics([2]). In our workshops, the approach seemed surprising to both teachers and students. We asked the students to come with questions about physics that we tried to answer *with* them, wherever possible, with *impromptu* demonstrations with everyday items for dramatic effect to capture their attention. We then linked these examples through further qualitative physical reasoning. This worked even remotely. The aim was/is to show how one can motivate discussion, illustrate principles, and stimulate further independent investigations through improvisation.

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([1]) The project commemorates our friend Alessandro Cilla.
([2]) We experimented with distance methods in December 2020 in cooperation with Istituto Pitagora (Montalbano, Basilicata), organized with Dr. Egidio Balice (teachers and selected students from the institute and also participants from our earlier sessions in Matera), and with Liceo Scientifico A. Volta (Ortona, Abruzzo, still in progress) organized with Dr. Paola Finizio.

Discussion

The DAD experience has shown that any experiments conducted remotely must be stripped to the bone. Lacking the comforting availability of pre-constructed equipment, students and teachers are now forced to reconceptualize the role of "experience" in understanding physical concepts. The central problem that emerged from talking with students is that they frequently see physics as a bunch of unconnected theorems, formulae, and vocabulary that are needed to solve examination questions without cross-referencing. The traditional physics curriculum proceeds in a pseudo-historical sequencing (except for, *e.g.*, [1]). It is easy to forget that this is *completely opaque* to the students. The passage from kinematics to dynamics is nearly unmotivated except as formalism, without any of the conceptual difficulties faced by the ancients and scholastic regarding space, time, and motion. Dynamics appears out of nowhere, beginning with the laws of motion but without the glosses of the *Principia.* Connections between the physics and mathematics are often obscured [2]. Most important, the epistemological step of associating a symbol —previously so casually manipulated in mathematics— with physical quantities involving units and consistency constraints, is encountered without preparation. Laboratory experiments are not that at all, they become demonstrations without curiosity and remain largely unconnected with the empirical origins of the formalism.

Ours is hardly a new idea. The first published example in Italian is still available [3]. It is useful to dip back into that book to realize that, in some form, *virtually all of the basic demonstrations to which we still submit students are there* but with instruments, constructed "on the fly" and measured with the crudest sorts of devices. Any case for which a student in a first physics class can solve an equation calculate is likely something for which she can create some example after discussion that yields the formal relation instead of the other way around. We will give here only a few examples, that certainly require preparation of attitude but use only the simplest materials. In fact, we argue, the more they are based on materials immediately at hand the better. This teaches that if a physical process is understood it should be possible to project —and create— a "verification". The result will certainly not be exact, it may actually contradict what seems otherwise flawless reasoning, but that helps to instill a critical sense, as a way to understand where the divergence lies. A crucial point is for the student to understand *error* as a source of scientific progress, and remind teachers how pedagogically useful that is. Even a student's frustration after an experimental failure to prove her idea becomes the seed for discussion. Curiosity requires stroking, recall Pasteur's dictum that "chance favors the prepared mind". Demonstrating a simple phenomenon that the students can then repeat for themselves cultivates critical thinking (especially if something fails) and analysis (to understand the result). Students benefit if a more formal presentation *follows* an *ad hoc* demonstration and preliminary *qualitative* analysis. This shows how to form a hypothesis, test an assertion, and the logic of theorizing. You can lead the student to see that, whatever the context, no verbal assertion should stand on its own without scrutiny. The converse is learning how to apply a principle or more qualitative reasoning to some physical observation before passing to quantitative analysis [4, 5]. "What if" questions do not originate from formalized, pre-packaged experiments. In contrast, a smartphone, or any digital camera, is ideal for observations and experiments, the images can be transferred to any computer for further analysis. There is no mystery about how the data were obtained or about the instrument(s) used. They are portable, so the student can be opportunistic, and the images can be shared and compared. That is, in any situation, whether it is an observation or an experiment, the students individually obtain data but can compare and contrast results of *independent* realizations. This is in sharp contrast to what usually happens in lab settings where the students work in groups, all taking the same data but analyzing them separately (essentially a numerical exercise since the results cannot then be meaningfully compared)([3]).

Examples

One effective approach was to assemble students in a gym, using different sports for demonstrations such as kicking a soccer ball or examining float service and attack in volleyball, as we did in Matera. Angular momentum was demonstrated with bicycles, not just the wheels or gyroscopes, to explain ordinary things like the procession of the frame on turning. This experience can be replicated by the students off hours, individually or (possibly) in groups. Another example was about elasticity. Instead of writing the equation for Hooke's law, tie weights to a rubber band, plot the extension, and translate that into an functional relation (including the inelastic, nonlinear regime). It is easy to avoid using the word "force" by comparing extension with weight (a far more familiar concept) which can be increased without specifying the weight in physical units by adding more of the same. These weights can, in turn, be *ad hoc* materials at hand, such as rocks or cans or whatever happens to be available. For the lever, the same reasoning was used by Archimedes [2], displacing the fulcrum to illustrate the ratio of lengths to show how the weight can be obtained (the inverse problem; the bent beam can be illustrated with a clothes hanger). A clear plastic Christmas tree ball filled to different levels with water illustrates the approach to neutral buoyancy. Using different fluids demonstrates specific gravity. Since these are equilibrium examples no timing is needed. Instead, for pendular motion the student can do the timing by taking their pulse, as Galileo did. The dependence on length is also easily —and surprisingly effectively— demonstrated by grabbing the string in flight at mid-point; the difference between initial and final heights is also obvious. A wooden stirrer or a thin ruler is an effective way to show how elasticity applies to beams but with the twist that the bending angle, not the extension, is the measured quantity (which also connects with the pendulum through bending moments). Bundling sticks show how the stiffness depends on the beam properties. Again, this can be done with weights without introducing any additional confusion regarding forces. But once the law has been determined, as in the buoyancy example, the inverse problem of measuring a force can be found by asking how hard the beam has to be pressed to produce the same deflection. A slinky or light metal spring hanging under its own weight and released in freefall is a way to illustrate the equivalence principle (and on an inclined plane dramatically extends the usual inclined plane example). The bibliography lists some especially useful inspirations. [6-9]

Conclusions

Most students of the last year of *liceo* know the *formula* of the period of a pendulum and virtually the *formula* for the force exerted by a spring, but far fewer are able to draw a connection between them. All of them expressed the same problem to make this kind of link: "*They have different formulas*". Teachers recognize the problem: textbooks are increasingly indistinguishable. Some provide pre-structured sheets to compile for laboratory experiences. Not infrequently, the teachers are reluctant to explain a topic differently than the textbooks, which are usually cumulative rather than integrative so

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([3]) For further examples, see the recorded presentation from 106th SIF National Congress (2020) `https://agenda.infn.it/event/23656/contributions/120775/`).

students often fail to connect the different applications of the same physical principles [4]. But before subjecting students to this pedagogy it is *essential* to train teachers to accept this approach and understand how to adapt it to their particular needs, to feel ready to improvise an answer or demonstration that connects natural phenomena to a *toy model* and link to the notions from the previous lessons. It is not a magic formula and cannot alone satisfy the learning needs of all students. Some will feel confused, inadequate, or lost, or uninvolved. But the teacher can tailor the approach to the students' needs and involvement. This has many advantages. The student learns ways to apply lessons in different subjects by linking them through phenomena. The teacher can be stimulated by breaking the routine presentation of the same topic every year, and teachers and students can work on experiments without a laboratory. Once accustomed to this approach and mindset, virtually anything can be used to examine, *e.g.*, rigid body and continuum mechanics, fluids, thermodynamics, sound, optics, and electromagnetism. Even the trash can become an useful source of instruments.

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