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Physics demos for all UVEG degrees: a unique project in Spain

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Abstract

The Physics Demo Project at the University of Valencia (www.uv.es/fisicademos) has developed a collection of physics demonstrations to be used during lectures. It consists of more than 130 experimental demos about different physics topics. More than 30 professors borrow them whenever they lecture on physics in any of our 40 courses in 17 different science or technical degrees, involving 246 ECTS and more than 3500 students. Each demo kit with a simple experimental set displays a particular physics phenomenon. An on-line user guide highlights the main physics principles involved, instructions on how to use it and advices of how to link it to the theoretical concepts or to technical applications. Demo lectures (and collections) are a usual and widespread practice in many countries but not in Spain. This unique initiative aims at the recovery of this practice by involving a growing collaborative team of users and with the aid of educational innovation projects. Here we explain the project content, organization and recent developments. Our experience, together with the positive students comments, allows us to draw the following conclusions: demos introduce the real sensible world in the lecture hall, providing the necessary link between concepts and everyday life, and becoming, again, something more than “chalk and talk”.

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Experimental physics demonstrations (or demos) are a resource for physics teaching with an important tradition in many countries. Physics demos are simple experimental devices that allow the observation of physical phenomena

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"in situ" in connection with theoretical or problem solving explanations, i.e., they are used to illustrate or introduce some topic before or after it is treated theoretically: we can see how things work in nature and ask ourselves how come they happen that way. Or identify the most salient features that can be immediately connected to our theoretical models.

The use of scientific and in particular physics demonstrations has a long history that we have previously addressed (Ferrer-Roca et al., 2012). They played a relevant role in scientific academies in the XVIIth - XVIIIth c., as well as in the popularization of experimental physics: demonstrations were even performed in lecture theatres or coffee houses and had a major impact on people who, like Faraday, later became great scientists and also lecturers with a keen interest in demonstrations.

Despite the importance of this specific physics teaching resource, and their good health in many universities (see the demo web sites in the Ivy league, for example. Some of them linked from our project site), demos are not currently a teaching/lecturing practice in Spain either at high school or university level. They are sometimes used and developed privately by interested and isolated teachers. But the idea that lecture demonstrations are an essential aspect of physics teaching was lost sometime in the past and it is lacking of any institutional (i.e. technicians, budget, etc.) or organizational support, as well as of a general interest in using this resource. We were not lectured in that way and we do not have the habit to do it ourselves.

Laboratories in our faculty are well equipped and our physics degree, for example, has specific laboratory courses separated from the theoretical ones. However, lab devices and practices have the scope of developing experimental skills; they are not conceived as an aid or support for conceptual understanding during the lectures.

This was the situation when the coordinator of this project started this demo collection at the UVEG physics faculty in 2006: few professors used to take some demos to their lectures, either subtracting some basic material from a forgotten laboratory closet or buying low budget consumables (magnets, Slinkies, etc.) at their own expenses. The establishment of competitive educational innovation projects in the UVEG (by the education innovation unit) allowed an initial impulse in 2007 that was increased and renovated in the following years till today. With the first available ready-to-use demos, some other lecturers joined the team and the project has been growing since, both in contents and users, with a positive feedback.

1. Not just a collection: recovering a teaching and learning experience

This project is not just about creating and developing an always increasing collection of physics demonstrations, but mainly about recovering and re-introducing a teaching resource that was lost, as stated previously. Some of our intellectual "grandfathers", professors belonging to two previous generations, can still remember being lectured with the aid of some physics demonstrations. We may wonder if the decline and fall of the demos in the lecture hall may be attributable to some kind of obsolescence. Our present interest in demos would be, thus, a historical one. But science demos are alive and in good health in many other places, and they belong to a teaching practice and tradition that has suffered no apparent discontinuities. This means that we are experiencing a sort of local singularity, in particular if we recall that the use of physics demos was one of the items introduced in the European Tuning Physics Project, considered a starting point for the harmonization of European university degrees (the so-called "Bologna process").

We can legitimately ask ourselves, why should we lecture using demos if students have probably seen them and discussed them at secondary (junior and high) school? But this is far from being the state of affairs: students study a combined chemistry-physics subject, with the exception of the last (pre-university) year, in which physics alone is optional for science students. Those who choose it, hardly do laboratory work at all. Thus, their physics background is often "chalk and talk", as demos are not a teaching practice and there is little contact with the natural phenomena and their theoretical explanation. Physics abstractions and formal mathematical models are powerful scientific conceptual schemes. However, they become little more than empty mathematical exercises or, even worse, provide confuse formulae in our students minds, as they cannot link them to the sensible world and its quantitative prediction. This is just the backbone of the scientific method.

Many students enroll our science and technical degrees (from nutrition and food technology, to pharmacy, environmental science, biochemistry, chemistry, electrical engineering, etc.) and all of them must follow a physics course in the first year. Around a 65% of chemistry students have not studied physics in the pre-university year. The same can be said of more than 85% of students following "bio" degrees and 95% in the nutrition degree. Moreover, 40% of engineering students come from professional schools with no physics subjects in the syllabus. In the first university year, many of them will attend little more than 45 physics lecturing hours and 10 laboratory hours.

In this context, demos can play a major role in the first year physics lectures, when studying the basic models and theories that explain consistently the experimental phenomena, improving their understanding. With the aid of demos we can also help students to develop a genuine surprise capacity before aspects of reality that are often before their eyes but they have never noticed. They can also understand the way science works.

So, from the beginning, this project has aimed at recovering a teaching practice that can improve our lectures and turn them more effective. Creating, maintaining and developing a physics demo collection is also a way of sharing and fostering a teaching style that is a powerful legacy. To put it bluntly: physics teaching has often been, and is, "chalk, talk and demo" (plus lab). Innovation in education involves also retrieving and readapting this resource (demos) that has served us well,. TIC resources open new possibilities combined with demos, that we have also developed in our project. But the basic learning objects are real devices, showing real phenomena. Computer simulations and videos are great complementary tools and find their own place in the learning process, but a live lecture, with a student standing on a platform that starts rotating just because she inverts a bicycle wheel, and a professor asking "why do you think this happens?" is a superior and unparalleled learning experience. This is, at least, what we can conclude from our students written comments (see point 5).

According to (Cofield, 2015) demos are becoming an ever more popular and important tool in inquiry-based teaching, the method of teaching by asking questions rather than lecturing. Bo Hammer, Associate Executive Officer of the American Association of Physics Teachers says that "demos lift the physics out of the textbook and make it much more real…and then the next step is to actually let students manipulate the demo or the device themselves. Then they start to get an intuitive sense of how things work." The only –and important- drawback is the fact that keeping and improving a demo set is very time consuming, as recognized by (Ehrlich 1990).

2. The demo set: contents, organization and uses

Currently our set of physics demonstrations consists of over 130 experimental demos related to different physics topics. They are stored in a set of shelves and cupboards, in the office of a laboratory assistant who volunteers to supervise the demos borrowings and returns, and alerts if some problem arises. This is not part of her ordinary duties. Each demo box kit includes a simple experimental set or device that displays a particular physics phenomenon to be observed and discussed and a printed copy of its guide. The budget assigned to this project allows only expenditure in consumables. So, many of our demo box kits are simple and small and can be easily taken to the lecture halls scattered in the campus. Different bags and shopping carts are available to facilitate transport. Just a few demos are based on unused recovered material instrumentation from different laboratories and some of them are fixedly mounted on a wheel cart as they included both delicate elements (i.e. electron beam lamps) and heavy ones (i.e. generators, etc.).

The demo set web page (www.uv.es/fisicademos) contains a catalog following a sequential order, as well as a classical order of physics topics: mechanics (20 demos), oscillations and waves (14), fluids (30), thermodynamics (19), electromagnetism (24), optics (17) and structure of matter and other topics (10). There is an online file hyperlinked to the name of every demo: a guide for users (professors using the demos and also students wishing to improve their understanding) including a description of the phenomena to be observed, the main physics principles involved, instructions on how to use it or link it to the theoretical concepts or to technical applications, and the expected outcomes, including some quantitative prediction, if possible. We also include the time expected, if any, to assemble the demo and some teaching advices on which information should we provide our students, before or after the demo has been used and the phenomena observed. These demo files, as well as other complementary materials, can be retrieved in the official UVEG open repository (RODERIC) and are subject to a non-commercial Creative Commons license.

The project team, which includes professors of all the physics departments, meets twice or three times during the year to decide new objectives (demos and complementary materials) and assign tasks. As stated before, there is no technical staff assigned to this project, so the demo set maintenance and improvement is the result of collaboration among peers. We all contribute and also benefit from each other's work. But this is not a private project. The demo set is considered a kind of infrastructure or resource in our faculty and is available to any lecturer. This is the differential element and the reason why this project is unique: no other university or physics faculty in Spain has, to our knowledge, such demo infrastructure and massive collective use.

There are 30 professors currently using demos in their lectures in 40 different physics courses belonging to17 scientific and technological degrees. They sum up 246 ECTS and more than 3500 students. There are around 330 registered borrowings each academic year, which means an average of 11 per person. Any professor in the physics faculty can borrow a demo from the collection, use it in her lecture and take it back. Some professors, do this more occasionally and others literally structure their lecture around some demo set, emulating (Borislav and Maiullo, 2009). Demos are also used in the master degree on secondary education (where no other experimental activity is scheduled) and in activities for secondary school students and teachers organized in the physics faculty ("Aula Experimenta" sessions, physics Olympiads, etc.)

In many cases the demonstration is the evidence of some important physics principle or law and becomes its paradigmatic illustration. So, in many physics courses, demos are not just observed and discussed using the theoretical background but they are included in exercises or homework, and become the content of questions in tests and exams.

Being able to explain real phenomena in physical terms is an important and recognized competence together with problem-solving exercises. Phenomena and the related physical laws are never isolated in the real world, it's our scientific effort to explain interplaying aspects of reality that lead to clearly distinct laws and principles. When students deal with the sensible world (real bodies, springs, generators, etc.) - for example, in the laboratory- they often expect to be in the same abstract world displayed on the blackboard, and discover that experience "works wrong"- whereas it is the other way round. If students end their science degrees with such simplistic ideas, we can truly say we have failed. Familiarity with real phenomena, with competing and often compensating effects, with the intrinsic complexity and richness we find dealing with reality, is an essential part of a scientific and technological competence. To say the least, being able to explain real phenomena is a good antidote against naïve views.

Demos are simpler devices than their laboratory counterparts and usually allow a qualitative observation of the effects of some changing magnitude at a time, and the conceptual and semi-quantitative discussions that follow. Some of them can be spectacular and act also as a memory trigger due to their impact.

3. Recent improvements: videos

Students can improve their understanding if demos are properly used and linked to the physics concepts. But when the lecture is over, the possibility to recall what they have observed and discussed - and cannot be found elsewhere- might be an important help. On the other hand, some phenomena can hardly be shown in the lecture hall (for example, launching a pressurized water rocket). In some cases phenomena change very quickly and they can only be observed and analyzed if slowed down. For these reasons, in the recent years we have started producing some videos on our physics demos that can be retrieved on-line in the open repository by lecturers and students alike. They range from elaborated films in which the demos are explained and linked with natural phenomena and technical applications (a narrator voice is on or someone appears giving explanations), to shorter videos in which a particular simpler phenomenon can be watched. They are not intended to substitute the real demos shown before students during the lectures, but above all, to be a useful complementary material for students. If some homework is given on a particular phenomenon that has been discussed, students can watch the video and think about it again.

A further development of this project will deal with the preparation of questions related to the demos. Conceptual questions are difficult to formulate when we face the interplay of real natural phenomena and the models to explain them. A collaborative work in this sense can be useful and lead to outcomes that can be shared by all and benefit students.

Both videos and conceptual questionnaires are a common practice in universities with a demo collection and in which demo lectures are a frequent.

4. The students response

Preliminary results from student opinion or so-called satisfaction polls are overwhelmingly positive. Around 200 students compiled the poll during the last semester in 2014-15. A 70% of students had never or scarcely seen any physics demonstration during secondary school, and 80% had never done any physics experiment during that period. The demos shown to them in their university lectures were strongly connected with the physical concepts (95%) and were explained in a clear and accessible way (90%). Lectures seem lighter and more enjoyable when demos are used (98%) and studying physics seems an easier task with them (80%). Some comments are specially encouraging and inspiring:

"Personally, I have been delighted with lecture demos and experiments and I think this was a general feeling. We were often looking forward to the physics lecture, just for the experiments. The lecture is nicer and more enjoyable and they arise more interest in the explained concepts. I think it's a great way to attract our attention and not be indifferent to an explanation. It's something like the answer to the question we often ask ourselves while studying: what is this useful for?"'. Well, it is useful for a lot of cool things".

"Demos during lectures are great, either for the highly useful devices used (fully equipped for car collisions, the turn table to the gyroscopic movement) and for the way the lecturers show them and explain them".

"The demo about the conservation of angular momentum with the bicycle wheel is the one I have liked the most. It is very interesting because it challenges our intuition and it is very useful to support this concept. I really believe that the possibility to see this demo during the lectures has greatly paved the way towards an understanding of the principle of conservation of angular momentum. Additionally, the lecture is more enjoyable and, in some way, it enhances inspiration or engagement in physics. "Small" things like these are something necessary on a daily basis ".

5. Conclusions

Through collaborative work and the aid of several educational innovation projects, we have created and developed a physics demo collection from scratch, intended as infrastructure or service at the disposal of all professors in the physics faculty who lecture in all the science and technical degrees at the University of Valencia. This is a common resource in many foreign universities but the first in Spain. Ready-to-use demo kits are complemented with open on-line explaining guides, videos and other materials that encourage lecturers to use them and work also as a permanent reference for students. The possibility to use demos during lectures help to improve the understanding of physics and lead to a change in the way we lecture. The students' comments follow this line and have been overwhelmingly positive.

6. Acknowledgements

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