Free software and free hardware to teach science: expEYES

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Abstract. Teaching science should always imply running experiments and give to the reality a chance to disapprove. If students do not run experiments, how can they know that it is science?
Unfortunately, experiments can be expensive. A school can lend books, but experimental hardware most often exists only in its laboratory. Hence, for some students, science applies only inside the classroom.
ExpEYES is a system based on FLOSS and Open Hardware, which is affordable enough to be lent to students, not unlike school books. It opens the way to learn science at a big scale, and also learn freedom.

Keywords: floss, open hardware, education, science, affordable

1 How can students know that they are learning science?

Let us dismiss the lazy answer: "because they are taught by their science teacher". My students know me as teacher of physics and chemistry. If their knowledge is based only on my course, they should definitely prefer famous authors.

For example, on the subject of the *rainbow*, they can get access for free to writings of Aristotle, Seneca the Younger, Alhazen, Averroes, Avicenna, . . . , Snell, Descartes, Airy, Mie. They just need to know one single keyword, *Wikipedia*, and click away reasonably.

However, during my course, they are given an opportunity to measure directly refraction angles, and all of them can compare theoretical predictions of Kepler, versus predictions of Snell and Descartes. There is a difference, and they can touch it. My wisest students can even conclude that the theories were not contradictory, but are making a trade-off between simplicity and accuracy.

The only way to know that we are learning science is to give to the reality a chance to disapprove our theories.

1.1 One example, from "big science"

The theory known as the "Standard Model"[Sutton(1994)], aims to describe all the matter in the Universe at microscopic scale. The budget of the CERN (more than 10^9 US dollars per year[CERN(2016)]) can be considered as a measure of the scientific community's effort to *let the reality disapprove the Standard Model*.

The experimental evidence of the boson of Higgs confirmed this Model in year 2012[CERN(2012a),CERN(2012b)], which brought a final point to a decades-long scientific quest; however some scientists feel disappointed [Moyer(2012)].

1.2 Experiments are mandatory

If we want our students to understand what science is, they must not only learn their lessons; they must also give to the reality a chance to refute their knowledge. If they don't, they can be learning scientism, which is a kind of religion.

Even if performing experiments is more expensive than just learning lessons, it is mandatory. Not all countries can afford equipment to allow most of the students to make experiments.

1.3 ExpEYES

ExpEYES is a box to make physic measurements, providing a solution to that issue.

Dr Ajith Kumar B.P, a scientist at Inter University Accelerator Centre, has been winner of Kenneth Gonsalves Award 2016 at Pycon India recently[PyCon(2016)]. He deserved this award after a long-lasting effort, known as "project PHOENIX *(Physics with Home-made Equipment and Innovative Experiments)*".

This short talk and demonstration is about the measurement box expEYES [Kumar(2016b)] which he created, as a free/libre open hardware[1], which enables an increasing number of students in India to run scientific experiments as an important part of their curriculum.

As a Debian Developer, I maintain the package `expeyes` for six years, and a live USB stick based on Knoppix[2] to facilitate its use.

2 Kits to teach science

All school laboratories are storing collections of hardware to enable teachers to make their job.

Some pieces in the collections are self-explanatory: for example, the main tool which I use to test theories about refraction is a half-cylinder of organic glass, correctly polished on the flat and curved faces which are crossed by ray beams. Nothing is hidden inside!

However, when we come to measurements implying voltages, this transparency is no longer the rule. Vendors of educational laboratory equipments

[1] ExpEYES is released under the CERN Open Hardware License (OHL)[Kumar(2016a)]

[2] Knoppix is a GNU/Linux distribution authored by Klaus Knopper (http://knopper.net); the live USB stick to facilitate the use of expEYES is known as Freeduc (http://usb.freeduc.org)

have developped "black boxes", painted with shiny colors, to perform such measurements. As nobody can sense directly a voltage, *who cares* about the lack of transparency?

In the annex documents below, there are examples of such black boxes, sold by companies National Instruments, Jeulin, Eurosmart. They are compared to expEYES whose design is free-libre. Suppliers of expEYES are not linked to a company: they can have the box built by any general electronics manufacture.

2.1 The need for transparency

When measurements are made under conditions close to the limits of expEYES' hardware, *artifacts* begin to appear, and the openness of expEYES' design lets experienced people know whether they are observing an artifact or something useful.

The same should apply to every other measurement box. When an experiment brings strange results, it can be exciting for the students who ran it: maybe something new for science? When the box is black, neither students nor teachers can know directly whether there is an *artifact.* **Why must the hardware and software design of scientific equipments remain secret?**

One angular stone of science is that experiments must be reproducible by anyone. How can we consider experiments making use of *black boxes*? When somebody wants to reproduce an experiment, must she buy the same *black box*?

2.2 Freedom entails new possibilities

Given the *same budget*, a school which has to buy measurement boxes for its science labs has two options: buy closed proprietary hardware and software, for teacher's use, or buy free-libre hardware to be used by all the students.

How is it possible? Companies selling educational hardware can keep their customers by many means: non-standard plugs, series of mono-compatible peripherals. The cost of migration is high, so competition is low. Free-libre designs are based on widely used and documented standards.

Here is a caricatural example: an "extension" to measure electric current. With Jeulin Tooxy (see below), one will buy the "current sensor"[3], which costs 60 € (and bargain to get a discount). With expEYES, one will buy a shunt resistor, which costs 1 € or less. The proprietary plugs of Tooxy prevent using such a simple solution.

2.3 ExpEYES + Freeduc = a complete free/libre tool for teaching science

The measurement box expEYES contains a free-libre firmware which allows the embedded microcontroller to perform measurements in real time. The main program used by end users is written in Python; so, its source is rather lightweight and can be understood by students.

[3] Jeulin Tooxy's current sensor: http://www.jeulin.fr/capteur-amperemetre-0-1-a-1-a-482202.html

Additionally, students can be assigned new rewarding tasks, like writing a program to monitor their experiment. Three or ten lines of source code are often enough to make a good job. See the examples below.

Freeduc is a GNU/Linux distribution available as a live USB stick. To boot Freeduc, all you need is a computer with an Intel-compatible CPU, and choosing the USB stick as an optional boot medium. Nothing is touched on the hard disk, and you are provided a fast and efficient desktop environment, with a rich set of applications for scientific students. All necessary software drivers, documentation, fifty examples, data processing programs, are provided.

Last but not least advantage: when a student knows how to boot Freeduc, she can have exactly the same scientific desktop wherever she boots that stick, in the school, at home, or in any computer room. A course about using expEYES and Freeduc[Khaznadar(2016)] is available inline under free license.

3 Appendix

3.1 Comparing measurement boxes

Vendor	National Instruments[4]	National Instruments	Jeulin[5]	Eurosmart[6]	various[7]
Product	USB-600[8]	USB-6003[9]	Tooxy[10]	SYSAM-V6B[11]	expEYES[12]
Analog inputs	8	8	2 “sensors”	2 “sensors”	5
Analog outputs	n/a	2	n/a	1	1
Accuracy, speed	12 bits, 10 kS/s	16 bits, 100 kS/s	nc, 10 kS/s	nc, 500 kS/s	12 bits, 100 kS/s
Digital i/o	4 + 1 counter	13 + 1 counter	n/a	n/a	6 + other signals
Price of hardware	$ 149	$ 499	$ 260	$ 429	$ 40
Control program	Labview[13]	Labview	Atelier Scientifique	(included)	free-libre, CRO+
Price of software	$ 999	$ 999	$ 68	$ 0	$ 0

3.2 Python programs to drive expEYES

Here is the simplest program usable to drive expEYES, with comments:

```
import expeyes.eyesj as ej # gets the driver module

p= ej.open()                 # p = pointer to the driver
print("Voltage on input A1 = {}".format(p.get_voltage(1)))
```

If one wants to plot an electric signal measured on input entry A1, with 1000 voltage values, sampled every 2 millisecond, the code can be:

```
import expeyes.eyesj as ej # import the driver module
from pylab import *        # import the plotting routines

p=ej.open()                # p = pointer to the driver
# measuring 1000 voltage values from analog input A1
# wait 2000 microseconds (2 milliseconds) between
# consecutive measurements
t,v = p.capture(1,1000,2000)

plot(t,v)                  # plots voltage versus time
show()                     # go to interactive mode
```

References

[CERN(2012a)] CERN (2012a) Cern to give update on higgs search. Press Release, http://press.web.cern.ch/press/PressReleases/Releases2012/PR16.12E.html, accessed: 2016-10-14

[CERN(2012b)] CERN (2012b) Update on the search for the higgs boson at cern on 4 july 2012. Press Conference, url-http://indico.cern.ch/conferenceDisplay.py?confId=196564, accessed: 2016-10-14

[CERN(2016)] CERN (2016) Budget overview. http://press.cern/facts-and-figures/budget-overview, accessed: 2016-10-14

[Khaznadar(2016)] Khaznadar G (2016) Affordable measurement box for science. https://github.com/georgesk/course-affordable-science/blob/master/course.org, accessed: 2016-10-16

[Kumar(2016a)] Kumar A (2016a) Expeyes is a free-libre open hardware. https://github.com/expeyes/expeyes-programs/blob/master/EJun/LICENSE.txt, accessed: 2016-10-15

[Kumar(2016b)] Kumar A (2016b) Main web site for expeyes. http://expeyes.in, accessed: 2016-10-15

[Moyer(2012)] Moyer M (2012) New higgs results bring relief—and disappointment. http://www.nature.com/news/new-higgs-results-bring-relief-and-disappointment-1.11837, accessed: 2016-10-15

[PyCon(2016)] PyCon (2016) Winner of kenneth gonsalves award 2016-dr.ajith kumar b.p! https://in.pycon.org/blog/2016/Winner-of-Kenneth-Gonsalves-Award-2016.html, accessed: 2016-10-15

[Sutton(1994)] Sutton C (1994) The standard model. CERN Courier, http://cds.cern.ch/record/1732288/files/vol34-issue5-p004-e.pdf, accessed: 2016-10-14