Check for updates

IN THE CLASSROOM

Experiments@home

Vittorio Saggiomo and Aldrik H. Velders

The coronavirus pandemic forced a rapid adoption of online learning. What can be done for teaching the practical elements of subjects like chemistry? Have we learned anything that we would keep outside of lockdown restrictions?

In March 2020, as lockdowns spread around the world like a virus, a simple question of 'And now what?' was echoed around the world by millions of academic researchers and teachers. While massive open online courses (MOOCs) seemed made for the occasion, the majority of us, ill-prepared for entirely online teaching, were left to fight with the likes of Zoom or Microsoft Teams. Low-resolution recording set-ups, random platforms for online exams and remote proctoring all contributed to the confusion. A few months in, however, and even the most hardcore and conservative chalk-and-blackboard professors were successfully delivering online lectures, armed with lighting systems, professional microphones, tablets and live Q&A over chat, all from their own kitchen tables. While lectures were shifted, it might be said relatively smoothly, from face-to-face to online delivery, laboratory classes were either partially or completely cancelled.

Laboratory classes, however, are an essential component of the curricula in most physical and life science courses. Synthesis, characterization and spectroscopic and microscopic analysis can be read about and described, but the hands-on skills are not acquired nor truly appreciated in this fashion. Hands-on experience is of paramount importance; it complements lecture-based learning and enables students to place theory in perspective. But how can we run laboratory classes while a pandemic is raging out of control? What follows is a short account of how we, at the Laboratory of BioNanoTechnology (BioNT) in Wageningen (Netherlands), faced the issue.

Between the first and second wave of the pandemic, in the early summer of 2020, we had a small window of time to prepare the classes for students for a minor in bionanotechnology in the first semester of the 2020/2021 academic year. As a result of the coronavirus-related restrictions, on-campus laboratory class hours were dramatically reduced to about 25% of the usual schedule. Teaching groups were split into parallel sessions in laboratory classrooms with a maximum of eight students present per room, and a selection of experiments from the curriculum were translated to the new settings.

Our minor in bionanotechnology at Wageningen University is delivered in three parts: Introduction, Nanomedicine, and Sensors and Devices. A typical introductory experiment we selected concerns the Turkevich-type colloidal gold-nanoparticle synthesis: gold salts are reduced by heating with citric acid in water[1]. For nanomedicine, cadmium-based quantum dots were synthesized and functionalized with protein-recognition elements, then applied in fluorescent diagnostic assays both in solution (flocculation) and on patterned surfaces (using microscopy). A planned excursion to the Interventional Molecular Imaging group at the Leiden University Medical Centre had to be cancelled, but online lectures were able to include footage from image-guided robotic surgery that allows surgeons to operate from their own computers at home! It was in the third part of our course — on sensors and devices — with new variants of SARS-CoV-2 emerging worldwide, that we anticipated further restrictions and put in place plans for a full off-campus laboratory class.

Our teaching philosophy has always drawn upon four elements: knowledge, imagination, creativity and inspiration. Our main goal in 2020/2021 of "BioNanoTechnology: Sensors and Devices" was to transfer the developing skills of creativity, critical thinking, and a problem-solving attitude from the teaching laboratories to something that the students could do at home. And so the idea of the Experiments@home box was born.

After an extensive safety screening, we decided to avoid organic solvents and use only chemicals that can be purchased in typical supermarkets or hardware stores and that are easily and safely disposed of. A second point of attention was the box size and amount of materials we could supply (FIG. 1). Many students live in shared houses, flats or rooms, and we were thus keen to minimize the invasiveness of the scheme. We set aside two full days in the students' schedules but left it up to them when to perform the experiments (that would occupy 4 hours per day).
We programmed in a few hours of virtual open door support, enabling students to drop in with questions or for explanations. We designed two different experiments, one focused on problem solving and one on stimulating creativity.

The first experiment involved the use of a simple, commercially available, paper strip sensor to quantify, colorimetrically, different analytes in urine. The students were provided with stock solutions of glucose and albumin, from which they had to produce dilution series to create a calibration curve. Pictures of the test strips were analysed using photos the students took with their own smartphones. This is not as simple as it perhaps sounds. The students soon realized that ambient light levels play a vital role in taking the picture and that black and white calibration spots on the pictures are useful to enable accurate quantification. Most importantly, they quickly recognized that molar concentration and total mass are very different by observing the mass sensitivity and saturation of analytes and/or sensor molecules on a strip. The students faced all these problems (and more) and attempted to solve them by brainstorming within their groups. As a test of their skills, we provided them with an analyte solution, the concentration of which they had to determine using their own calibration curves.

For the second experiment, focusing more on creativity, we provided the students with a cheap microcontroller (Arduino) and a colour sensor and asked them to build their own colorimetric and fluorescence sensor to detect changes in pH and fluorescence. Experience with microcontrollers, programming, 3D printing and, in general, a do-it-yourself approach, although increasingly important in research[2,3], remains absent from the curricula of many (molecular) life science students. In our experiment, students were also encouraged to design their own 3D-printable set-ups — which we were able to print in our labs for them to collect. They thus had to face and solve different problems, ranging

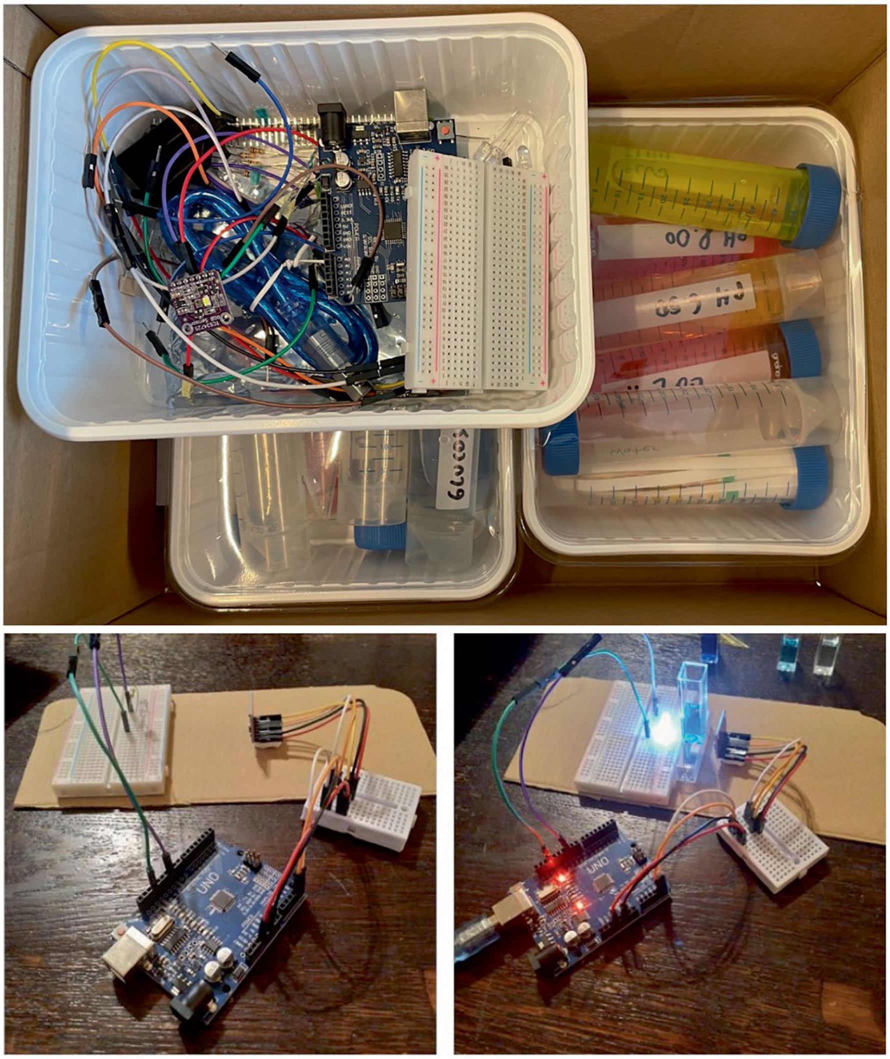

Fig. 1 | **Photographs of the Experiments@home kit.** Top: the ready-to-distribute kit, including standard and test solutions, electronic components and consumables. Bottom: colorimetric and fluorescence detection devices built by our students.

from determining the optimum distances between the sensor, the light source and the cuvette, through the colour of the LED light to the most effective 3D design. As in much of our bionanotechnology minor, the students were given ample room to experiment with their own ideas. Indeed, we feel strongly that students should not be penalized when an experiment does not work as planned. The process of identifying an error or mistake, understanding its source and planning improvements is, for us, arguably more important than performing a successful experiment that may lack understanding. Such an approach can be rewarding for both students and teachers. In our 2016 course, students working on a version of the aforementioned gold-nanoparticle synthesis experienced problems as a result of a loosely prescribed protocol. The result, however, was the production of dichroic nanoparticles that were then further investigated and incorporated in 3D-printable polymers that were used to make mimics of the famous ancient dichroic glass Lycurgus cup[4,5].

In both experiments, it was important to frame the experiment, providing both a goal and a challenge. We firmly believe that an interested and engaged student is a happy student, which cannot be undervalued in lockdown. We decided to detect changes in pH and fluorescence because both are commonly applied in nucleic acid detection protocols that have become ever more important during the COVID-19 pandemic. With real-world applicability in mind, we challenged our students to design a set-up able to detect these changes in a 200 µl PCR tube — which is used as standard in nucleic acid amplification. Again, we left the students ample room to experiment, with some designing new 3D-printed holders for the PCR tubes, while others tested home-made filters from plastic or glass bottles they had available at home. Our adaptation of our minor in bionanotechnology, in particular the subsection on sensors and devices, was planned in haste and, with the benefit of hindsight, many things can be improved. 2020 was surely a difficult year for everyone, with university students suffering some of the most upheaval. With this course, we attempted to bring a university teaching laboratory into the students' own home, an effort that was both highly appreciated and applauded by the students.

Even without the lockdown, the Experiments@Home is there to stay, and even to be extended. In normal laboratory settings, our sensors and devices students would usually work on arsenic sensing with nanoparticles. For perhaps obvious reasons, this experiment was not included in our first iteration of our Experiments@Home kit. However, considering that the dose makes the poison, we do not feel that such home experiments are entirely out of reach. In addition, one of our major research themes concerns the development of open technology and we hope to expand in this direction. We have, for example, developed technology for microfluidics and actuators experiments[6,7] that are already suited for hybrid (combined on/off campus) laboratory classes and sometimes readily implemented in at-home experiments, with little need for chemicals harsher than typical nail-polish remover.

Vittorio Saggiomo ✉ *and Aldrik H. Velders*
Wageningen University, Wageningen, Netherlands.
✉*e-mail: vittorio.saggiomo@wur.nl*

https://doi.org/10.1038/s41570-021-00285-2

1. Turkevich, J. Colloidal gold. Part I. *Gold Bulletin* **18**, 86–91 (1985).
2. Kwok, R. Field instruments: build it yourself. *Nature* **545**, 253–255 (2017).
3. Ravindran, S. How DIY technologies are democratizing science. *Nature* **587**, 509–511 (2020).
4. Kool, L. et al. Gold nanoparticles embedded in a polymer as a 3D-printable dichroic nanocomposite material. *Beilstein J. Nanotechnol.* **10**, 442–447 (2019).
5. Kool, L. et al. Gold and silver dichroic nanocomposite in the quest for 3D printing the Lycurgus cup. *Beilstein J. Nanotechnol.* **11**, 16–23 (2020).
6. Saggiomo, V. & Velders, A. H. Simple 3D printed scaffold-removal method for the fabrication of intricate microfluidic devices. *Adv. Sci.* **2**, 1500125 (2015).
7. Velders, A. H., Dijksman, J. A. & Saggiomo, V. Hydrogel actuators as responsive instruments for cheap open technology (HARICOT). *Appl. Mater. Today* **9**, 271–275 (2017).

Competing interests
The authors declare no competing interests.