Breathing new life into the biology classroom

An increasing number of exciting experiments for teaching biology is becoming available, but teacher training and institutional reform are also needed to integrate them into curricula

When asked what they remember of their biology class in school, most biology teachers will recall hours of tedious dictation, poring over thick tomes and intricate drawings of dissected, half-putrefied animals lingering in formaldehyde. Few will reminisce about memorable experiments, in contrast to chemistry or physics. Given this background, it is not surprising that many teachers find it hard to get to grips with experiments in molecular biology. The classroom is already in danger of being superseded as a source of educational material by the Internet, while teachers are faced with students who are increasingly difficult to motivate. But on one thing all teachers agree: children love experiments. As Dean Madden, Co-director of the National Centre for Biotechnology Education in Reading, UK, exclaimed enthusiastically at EMBO's second international practical workshop for science teachers earlier this year, "children love to get their hands dirty." And the simpler the experiment, the better, it seems.

However, dragging a slowly decomposing cadaver from a bag of yellowing liquid to dissect another part of its anatomy is not the kind of hand-dirtying that most students look forward to. They might, for instance, find it more interesting to explore some of the practical science behind the ground-breaking and socially controversial technologies made possible by molecular biology. But the terms 'molecular biology' or 'biotechnology' alone cannot magically conjure an exciting experiment out of thin air. Whether it is a simple experiment done with minimal equipment in the school laboratory, or a more advanced one in a teaching laboratory at a research institute, an experiment must stimulate curiosity beyond the technicalities of pipetting solutions and running gels.

And there is an urgent need to stimulate this curiosity about biology among the younger generation; first, because citizens increasingly need to be equipped with the intellectual capacity to play an active role in deciding their future, and second because society needs excellent young scientists to push the frontiers of research. Making science an attractive subject, and cultivating an enquiring mind, both start in school. But biology is not a textbook subject that can be learnt merely by rote, or studied as a history of knowledge. It is a rapidly developing field of science that relies on experimentation and critical evaluation. It is a science that requires every bit as much brilliance in its practitioners as other sciences, and by inference, every bit as much attention to their education. Sadly, in many European secondary schools its teaching has not kept pace with modern research.

Biology experiments in schools have always come a poor second or third to chemistry or physics because they are often slow and boring, and do not bring immediate rewards. The problem can be summed up fairly simply: biology experiments, unlike chemistry or physics experiments, do not whizz around spewing sparks, levitate in thin air or explode—that is, unless one accidentally short-circuits a power supply. When was the last time that a student gaped in awe at a school biology experiment? Not recently, in all likelihood, but that could be about to change.

Teachers are increasingly being offered experiments that evoke this so-called 'wow' factor. Green fluorescent protein, for example, is not only a wonderful research tool, but also a godsend for teachers. Gene expression, a topic that must be covered in all curricula, can best be exemplified by an experiment that

Biology experiments in schools have always come a poor second or third to chemistry or physics because they are often slow and boring, and do not bring immediate rewards

results in a Petri dish of glowing green bacterial colonies. At least one biotech company, Biorad (Hercules, CA, USA) has capitalized on this with the production of a school kit (Fig. 1)—although a similar kit is still freely available from a pioneer in the education world, the Dolan DNA Learning Center at Cold Spring Harbor Laboratory, NY, USA. Such solutions are convenient for teachers because they can almost guarantee a result if the instructions are followed. And this is crucial, explained Dominic Delaney, Bio-Rad's BioEducation Project Manager in Hemel Hempstead, UK: "Science in the classroom is brutal: you're dead if the experiment doesn't work first time." Another conveniently packaged experiment from Bio-Rad is the solving of a murder mystery by restriction digest DNA profiling. Both experiments can be done in blocks of 50 minutes, which fits well with school timetables.

And those who do not regard biology experiments as an 'electrifying experience' should perhaps try the microbial fuel cell, developed by the National Centre for Biotechnology Education (NCBE), Reading, UK. With good preparation, the cell produces enough power at the end of a double lesson to run a small electric motor. The cell itself must be obtained from the NCBE for about €60, and can be easily used by teachers to demonstrate electron flow through the yeast respiratory chain.

In addition, laboratories outside school can provide a project-based environment in which to learn practical molecular biology, such as that offered by the teaching laboratory Xlab in Göttingen, Germany. A model in many ways, Xlab offers practical experiments, term-time courses and holiday courses for students and teachers in Germany and abroad. And these are certainly no 'run-of-the-mill' practicals. One recently developed experiment involves tracing the origins of European peoples by PCR analysis of mitochondrial DNA. Drawing the innards of a dismembered earthworm just does not compare. According to Eva Maria Neher, founder and director of Xlab, students' interest in practical work is largely cultivated by "a tutor who bubbles over with enthusiasm for a method about which hardly any scientists give a second thought. One can only communicate excitement [to students] in things about which one is also excited." And the same holds true for school teachers, of course.

But children do not have to leave the school lab to experience such fascination. An old favourite is the isolation of DNA from fruit, which can be done with mere household objects and reagents. As a teacher from Germany remarked, "when they pulled out the slimy thread from the tube and realised that it was DNA, there was a whispered chorus of 'wow'." Indeed, although distribution and sharing of equipment in schools is the ultimate goal, a little ingenuity could certainly help to oil the wheels of progress. A €200 micropipette can be improvised from a glass capillary tube and some wire. An agarose electrophoresis kit that costs about €400 can be made from a Tupperware box, some wire, silicon sealant and five 9-V batteries (www.accessexcellence.org).

In general, biology teachers need a mixture of experiments that can be done with minimal equipment at school, ones that can be performed with scientific support and, finally, ones that they may never actually do, but that extend their horizons. Furthermore, the school laboratory should retain a central importance in the education process. It is here, after all, that children first get a taste for experimentation in an uncomplicated way. The school lab cannot be replaced by extramural experiences in practical science. However, there is a danger that it may become neglected as science museums, visitor centres at universities and tailor-made laboratories create an ever more comprehensive offer.

Fig. 1 | Illustrating gene expression with Bio-Rad's green fluorescent protein kit for school teaching

To ward off this impending obsolescence, it is necessary to modernize school laboratories. Teachers must acquire the skills and confidence to coordinate a new kind of practical class at school, and be allowed to use their own creativity. For Stefanie Denger, a research scientist at the European Molecular Biology Laboratory in Heidelberg, Germany, who is intimately involved with education and communication initiatives, the way ahead is clear: "Teachers need to make personal contacts to scientists and build up their confidence."

In southern Germany, some motivated teachers have already taken the matter into their own hands with, as yet, minimal funding. The so-called 'Stützpunktschulen' (regional support schools) in Baden-Württemberg act as training centres for other teachers and distribution points for loaned equipment. The scheme revolves around individual teachers, who are given a small—1 hour per week—time allowance out of their statutory teaching hours to run the service. They form the link between academic research institutes and the school system, train other teachers and hence spread their expertise. Furthermore, it is recognized by an official office: the regional education authorities. Peter Gilbert, the school system's director at the Oberschulamt Karlsruhe, is a key figure in promoting the Stützpunktschulen and in trying to secure their institutional funding. He noted that they can also provide scientists with useful communication channels: "Scientists can go to a school with a concept that they think important, and ask 'how can we work together on this?'"

> A €200 micropipette can be improvised from a glass capillary tube and some wire

The Stützpunktschulen complement a growing number of individual contacts between research institutes and schools. But, in general, such initiatives are not formally recognized by official bodies, either nationally or in Europe, and hence receive no institutional financial support. The problem naturally arises as to who pays for the equipment that is needed to do simple molecular biology experiments. The schools are invariably penniless. Ironically, the equipment they need—gel tanks, mini centrifuges, power supplies, waterbaths and pipettes—is decommissioned by research institutes by the dozen every year. Instead of allowing these resources to linger in storerooms, some have started to assemble them into pools that can be used by teachers. The only problem is that very few teachers know how to use them, and even fewer wish to take responsibility for them.

Perennial questions are: who is responsible for such apparatus when it leaves the research institute? Who repairs it when it goes wrong? Who services it and guarantees that it is safe to use?

But if complacent Western European schools cannot solve these problems, then there is nothing stopping teachers in the Ukraine from welcoming second-hand equipment from western research labs. After all, research institutes are already doing it with the help of the Federation of European Biochemistry Societies (FEBS). As Lesya Hurtenko, a biology teacher from Smila in the Ukraine, said: "I think it is manageable, and we will have support from many people on different levels. I see myself that experimental work stimulates pupils to learn more, and it is very important to give them this opportunity." Indeed, Eastern European countries have started their own initiatives to raise school students' interest in modern research. For example, the Hungarian Network of Youth Excellence has provided more than 7,000 high-school students from various Eastern European countries with an opportunity to do research in a university laboratory.

Fig. 2 | DNA models and molecule building kits for teaching

In the school laboratory, it is important that teachers have the freedom to organize teaching as they see fit, and can use larger time-slots for experiments. As Rainer Domisch, the Finnish governmental advisor for Education, remarked, "Systems must accommodate people; a system should not exist for its own sake." He believes that "the models and experiences of Finland can certainly be applied in larger countries." But the profound reforms responsible for Finland's success were started 30 years ago, so this will be no quick fix for others' systems and curricula. One can tell a lot about the freedom of the system from the length of the curriculum, Dominic Delaney asserted: "in Denmark it is 1 page long, in the UK it is 80 [...] this suppresses teachers' tendency to do riskier things like new practicals."

In contrast to the egalitarian Finnish model, the USA starts with an elitist principle that eventually filters down. Their so-called 'Advanced Placement Biology' (AP Biology) has been around since the 1970s. Although the programme, containing much practical work, is an optional syllabus, it has resulted in many US schools having basic molecular biology apparatus as standard, thus spreading this resource to normal biology classes. Here, teacher autonomy and money—some from federal funding and some from school-organized fundraising events—were the keys. As David Micklos, Director of the Dolan DNA Learning Center, remarked: "Teachers have a good deal of autonomy on what they can teach, and simply went out and bought these things" (Fig. 2). Equipment is shared between schools and administered by local universities with outreach programmes. The examinations in AP Biology are administered centrally by Princeton University—an obvious mark of quality. In a similar way to the Stützpunktschulen, Micklos noted that "Some teachers set themselves up in labs in their schools as experts." Experiments, discovery and flexibility are crucially important to the co-author of the renowned text book *DNA Science*: "I see standardised tests as an anathema to any kind of excellence." Unfortunately, if you have a system that relies on standardized tests, doing practicals is the least efficient way of learning facts to pass those tests, Micklos observed.

> The problem naturally arises as to who pays for the equipment that is needed to do simple molecular biology experiments

Clearly, a large part of the solution to the difficulties of the school laboratory lies in the triad of teachers, research scientists and science education establishments, but institutional support and reform remain crucial. Unfortunately for many, no matter how impressive and convenient it is to perform an experiment, if it cannot be used to teach part of the curriculum, it is as good as useless. Thus, a large part of the success of any proposed solution lies in the increased confidence of teachers to perform new experiments, to push through new practice and to get their work recognized at a higher level. Support from scientists is invaluable in creating this new confidence, and should be considered as the start of the road to reform.

Andrew Moore

doi:10.1038/sj.embor.embor907