Hands-on Science

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Introduction

In 2005 the Secretary of State received a report from the Higher Education Funding Council for England (HEFCE) that identified Science, Technology, Engineering and Maths (STEM) disciplines as both strategically important and vulnerable. Their vulnerability was measured by a mismatch between the supply of suitably qualified graduates from higher education and the demand for such graduates from UK industry and commerce. The problem becomes clear if we look at the numbers of young people entering higher education to study STEM disciplines. Data show that the numbers entering first year degree programmes have, at best, remained steady over the past twenty or so years. This covers a period of rapid expansion in the numbers of 18 year olds entering higher education. Therefore, the STEM disciplines have seen a real and drastic reduction in their market share of the cohort.

It is enlightening to look at the numbers of applications for undergraduate science courses versus numbers of acceptances for such courses. For example, in 2007 15,567 people applied to study physical sciences through the Universities and Colleges Admissions Service (UCAS). However, 15,801 finally accepted places in such programmes. Thus, more undergraduates are accepted on physical science programmes than originally applied for places, suggesting that many of them may not even be very committed to their programme of study. This mismatch is probably due to the large numbers who apply for but do not get accepted onto courses such as medicine and veterinary science.

We look to the teaching profession to inspire our next generation of scientists. However, it is well known that there is a chronic shortage of specialised teachers of chemistry and especially physics and many pupils are not taught science by a subject specialist. The numbers of entrants to Post Graduate Certificate of Education (PGCE) courses has remained very stable despite the introduction of incentives such as the 'golden hello'. It is crucially important that enough well-motivated, enthusiastic scientists enter the teaching profession if the number and quality of undergraduates entering Higher Education (HE) is to increase to meet the demands of commerce and industry.

These issues are being tackled in some ways. The enhanced 'golden hello' for trainee teachers may not be increasing the numbers entering the profession but it may well be increasing competition for places of PGCE courses which in turn will mean that the better qualified applicants are recruited. There are several support mechanisms for science teachers to enable them to take part in Continuing Professional Development (CPD) and to improve their skills. In addition many organisations are now engaging directly with schoolchildren in an attempt to enthuse them about science.

Support for science teachers

The Association for Science Education is a professional organisation that exists solely to support science teachers and to improve the quality of science teaching. The Association runs a number of very successful conferences and publications and has a wide membership from within the teaching profession.

Science Learning Centres are a national network for professional development in science teaching. The Centres support teachers in enhancing their professional skills by learning more about contemporary scientific ideas and in experimenting with effective teaching approaches and gaining experience of modern scientific techniques. Their challenge is that they have to charge for their services and that teachers often have difficulty being out of school to attend events.

Most of the professional bodies such as the Institute of Physics and the Royal Society of Chemistry provide resources for science teachers to use in the classroom as well as offering opportunities for in-service training.

Universities are increasingly offering support to teachers by offering events for pupils or conferences and resources for teachers themselves. Industry also provides many teaching and career education resources.

The relatively new regional STEM Centres are attempting to bring together all the offerings in support for STEM in a 'one stop shop' approach. They provide a single contact point for teachers looking for support for any area of the curriculum.

Direct interaction with school children

Academia, industry, professional bodies and other organisations are increasingly becoming involved with direct interaction with schoolchildren in an attempt to turn them on to science. Their approach is usually via curriculum enhancement and enrichment activities with a focus on providing access to exciting hands-on activities. These activities also often provide positive role models and some insight into science-related careers.

A selection of 'hands-on' focused projects is described here:

'Hands-on science' is an EU Socrates Comenius-funded project that aims to promote experimental teaching of science as a way of improving in-school scientific education and science literacy in society

'Hands-on science' is also the title of a Higher Education Funding Council for Wales (HEFCW) funded project that aims to promote, enthuse and increase the number of pupils studying science, maths and health-related subjects beyond the General Certificate of Secondary Education (GCSE).

'Chemistry: The Next Generation' is managed by the Royal Society of Chemistry and funded by HEFCE. It aims to promote the excitement of chemical sciences and demonstrate good career opportunities.

'Stimulating physics' is managed by the Institute of Physics and funded by HEFCE to increase the number of people taking physics courses at A-level and degree level.

The HEFCE funded 'London engineering project' aims to alter the student uptake into engineering courses, provide tomorrow's engineering workforce, allow London students to claim their place in the technology-based future of London.

The HEFCE-funded 'Moremathsgrads' aims to develop, trial, evaluate means of increasing the numbers of students studying maths

Several universities have dedicated Science communication units. These include the Universities of Surrey, Liverpool, University of the West of England, Bristol (UWE), University College London (UCL), Imperial, Bristol, Royal Holloway.

The Engineering and Physical Sciences Research Council and the Science and Technology Facilities Council also encourage public engagement and schools programmes.

The British Association for the Advancement of Science (BA) exists solely to advance the public understanding, accessibility and accountability of the sciences and engineering and organises an annual national science week and Festivals of Science.

From the HE sector over 100 universities engage in STEM outreach activities. These work with the primary, secondary, Further Education (FE) sectors and focus on curriculum enrichment with hands-on, whizz-bang activities. Their aim is to raise aspirations in science, to provide positive role models and of course have one eye on recruitment for the future.

Is it working?

Overall, there is a great deal of direct involvement between various agencies and school children associated with hands-on science activities. There is little evaluation of the long term impact of these activities but there is some evidence from the published research literature which should inform these activities.

In 2005 the Oxford, Cambridge and Royal Society of Arts Examinations Board (OCR) carried out a survey of 950 year 9, 10 and 11 students. They found that 50%+ students thought that science is boring, confusing, and difficult. 25%+ of the group indicated that they would not progress beyond GCSE. Experiments were the most popular activity followed by field trips. Reading textbooks and research on the internet were the least popular activities.

In 2002 a survey of 218 physics undergraduates (in Scotland) investigated the factors that affected the students' choice of discipline to study at university. It was found that 87% cited enjoyment of subject, 47% cited career opportunities, 27% cited the teacher and only 9% cited demonstrations, festivals, exhibitions and visits (Reid and Skryabina, 2002).

Research by Jarvis (2002) investigated the effects of a visit to a science centre or similar on the attitudes of pupils. It was found that positive attitudes following interventions only persist beyond a few weeks if pre- and post-activities are carried out by teachers in school.

Summary

There is no doubt that we need to switch more young people on to science. Research evidence clearly tells us that experiments are the most popular and most effective vehicle for achieving this. Research also indicates that it is what happens within the school curriculum that is most influential in determining children's attitudes. External efforts can enhance and enrich the curriculum but the school science curriculum and the teachers that deliver it are the only effective vehicle for changing attitudes in the long term. Therefore, we need more creative, enthusiastic, confident science teachers and we must create space, time, and facilities for more hands-on science in schools.

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Hands-On Science in Schools: The Enhancement & Enrichment Perspective

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Within the UK there are a remarkable range of programmes and activities on offer which seek to enhance and enrich student experience of science in school. Offered by a wide range of organisations, including universities, learned societies, museums, charities and private companies (both large and small), the impact of these programmes is arguably greatest when the students are most engaged – and one of the most effective ways to achieve that engagement is through hands-on learning.

This article will consider three separate case studies of successful Enhancement & Enrichment (E&E) initiatives. The purpose is to provide a snapshot of the range of activities that are available, as well as highlight key features which lead to success. Challenges associated with E&E activities are also discussed, and a range of exciting new developments in the field highlighted.

Case Study: RoboCupJunior

RoboCupJunior[1] (RCJ) is a project-oriented educational initiative that offers local, regional and international robotics events for school students. It provides a unique opportunity for participants with a wide variety of interests and strengths to work together as a team to achieve a common goal. RCJ offers several competitions, each emphasising both co-operative and task-achievement aspects:

In **RoboDance**, one or more robots perform to music, optionally accompanied by the students. This allows considerable scope for artistic creativity and is particularly appealing to girls.

In the **RoboRescue** challenge, robots race to identify 'victims' within simulated disaster scenarios.

The **RoboSoccer** game involves a dynamic environment in which teams of autonomous robots play on a greyscale pitch using an infrared emitting ball.

From the excitement and sheer enthusiasm of the teams involved there is no doubt that they enjoy the competition. However is it actually of benefit educationally? Petre & Price (2004)[2] are in no doubt of its effectiveness for 'back door' learning. They observed and interviewed teams at all levels of the competition, concluding that:

"…many of the children revealed that they had come to terms with topics (such as programming, gearing, and mathematical representations) which they had previously found difficult, in order to make the robot work. ***That drive*** *to build a functioning robot* ***had carried them into new*** *and sometimes daunting* ***territory****. It had helped them to take step-by-step and systematic approaches to* ***learning what they needed to know.****"*

The researchers also reported that learning encompassed an impressively broad range of skills, ranging from problem solving and planning to improvisation, learning from mistakes, teamwork, information sharing, interpersonal skills, and even patience. There is also evidence of this hands-on learning style appealing to a wider range of learning styles and educational needs.

Case Study: Awesome Athletes

The immersive learning approach which RoboCupJunior achieves through the incentive of a competition can also be accomplished in other ways. **Awesome Athletes**[3] is a programme of 'theme days' for primary children developed by the University of Nottingham, based around the topic of 'movement'. The programme encompasses a cross-curricular approach that stimulates engagement through problem solving, creative thinking and investigative learning. The delivery team work in close partnership with each school to develop a tailored programme that is fundamentally 'owned' by the school. The result is that the pupils' experience is directly linked to the world of R&D; teachers and children alike are excited and inspired by the idea of doing something similar to real research.

Feedback from schools has been outstanding; not only do the pupils enjoy the activities but there is clear evidence of both educational learning and improved attitudes towards science:

"The children enjoyed what they did and learned the best way, through hands-on experiments. Many commented that this was the most fun they had in science and wished it could be like this all the time!" – Parent Governor at Middleton Primary School.

"Do you know, I quite like being a scientist" – a normally unmotivated child from Lambley School

Perhaps the best outcome however, has been the evidence that a single theme day or workshop has changed the attitude and teaching practice of many teachers towards science and engineering.

"Encourages a more thematic, process-orientated. open-ended learning/teaching and working with cross age groups." – London teacher's workshop delegate

General feedback from teachers has indicated that the theme days provide an exciting and inspirational focus for the students, which has longer term benefits. For example, the children talk about the event weeks later, make reference to being a scientist themselves and make links with what they are doing in science class and what they did during the activity.

Case Study: Meet the Gene Machine

The first two exemplars built upon direct hands-on interventions, however there is also a wider implication of 'hands-on' that is worth considering, particularly in the case of older students. There is a great deal of evidence [4] to suggest that teenagers become more engaged with science when they are encouraged to consider – and actively debate – the social and ethical implications, rather than just the hard facts, leading to recent changes in the curriculum [5]. Meet the Gene Machine [6] is a current activity being delivered in schools by science centres throughout the UK. It aims to provide young people (aged 14+) with an opportunity to think about, discuss and debate relevant social, moral and ethical issues relating to genetic testing. In addition to the drama/debate with students it incorporates twilight Continuing Professional Development (CPD) sessions for teachers as well as a comprehensive pack of resources for teachers to use themselves within class.

To date the programme has reached over 9,000 pupils and over 380 teachers, and teacher reception of the project has been outstanding:

- 98.4% agreed that the activities within the discussion were useful
- 99.2% agreed that it was good use of students' time
- 100% agreed that they would involve students in a similar event again

Successes of Hands-On Science E&E

Comparison of the three case studies highlights certain key features which are critical to success:

- *interactive, participatory* – the 'hands-on' nature adds significantly to their success
- *cross-curricula approaches* – students and teachers alike are stimulated by activities which emphasise science in a broad context
- *clear curriculum links* – schools are finding it increasingly difficult to justify activities which are not clearly linked to the curriculum
- *building on existing networks and partnerships* – inspiration, relevance and coherency are best achieved through activities which combine specialist external expertise with internal teacher input, and take advantage of existing networks
- *sustainability and transfer of ownership* – the most effective way to reach as many students as possible is to embed the activity within a school; this is best achieved through developing teacher's skills and confidence to take ownership and adapt it to suit their own teaching

Challenges and Steps Forward

By the same token, certain issues do still remain which need to be accommodated:

- *teaching time is precious!* – Schools may not be in a position either financially or due to timetable constraints to release students for participation, or teachers for training. It is also often difficult for teachers to be able to identify where to source appropriate E&E activities; this is currently being addressed through the provision of the STEM Directories [7].
- *frequently reliant on volunteers* – Many providers of E&E activities do so on a voluntary basis, and often their E&E activities are unappreciated within their 'normal' jobs. In the long-term case of research staff in higher education this issue may be ameliorated with the advent of the Beacons for Public Engagement [8].
- *funding continuity* – It is rare to receive public engagement funding for more than two or three years, meaning that even very successful activities often have to close.
- *difficult to identify longer term impacts* – Partly due to the short-term funding structure, there are few longer-term studies of the impact of E&E activities on student subject selection and retention within the sciences.
- *audience reach* – Due to the nature of these activities they are often taken up by highly motivated teachers, which can mean that pupils in disadvantaged areas miss out. There are specific programmes to address this imbalance, eg Aim Higher [9] or the London Engineering Project [10].

Conclusion

It is not within the scope of this text to outline every current development within the field; however there are a wide variety of exciting initiatives. There is a phenomenal range of excellent Enhancement & Enrichment provision available within the UK, particular in the area of hands-on science. The challenge is to learn from previous key projects to ensure that students of the future receive the best possible experience in science.

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HANDS-ON SCIENCE IN SCHOOLS

Remote Experiments

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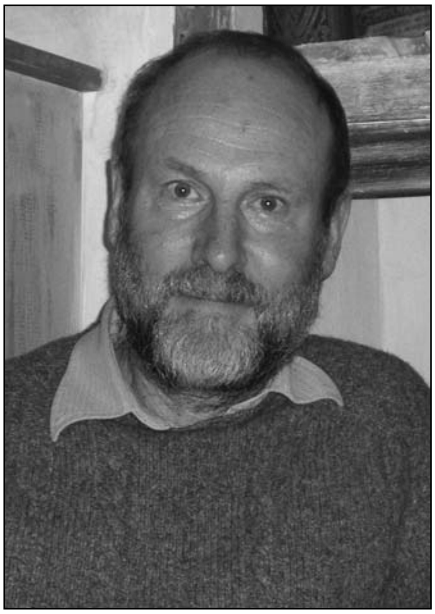

Some people have a 'feel' for science. When they encounter a new problem in the physical world, they may know almost instantly how it could be solved, or at least have a hunch about what a solution would look like, even if they have never met it before. Using an ability to 'think outside the box', observation and theory can be linked in ways that others have not considered.

This sort of instinctive understanding is not as rare as one might imagine – many of the most productive scientists seem to possess it – and it is particularly valuable when scientific progress requires knowledge of more than one field. Medical imaging, biophysical chemistry and forensic archaeology are examples of applications in which research is facilitated by an understanding of at least two distinct fields.

If it is so valuable to be able to think about science intuitively, we should promote and nurture this ability among our young scientists; how might this be done? Science is inherently experimental, and an interest in science (or a lifelong hatred of it) generally develops in primary and early secondary school, when science teaching is frequently illustrated with experiment. If, through experiment, children can 'play around' with scientific ideas as they meet new concepts, they are more likely to acquire this feel for how the natural world behaves.

In the world of science fiction, eager science teachers unwrap modern equipment to illustrate and enliven each new topic as it is introduced. In real schools, equipment is limited in scope and quantity, is often well beyond its use-by date, and might have been inappropriate for its intended purpose even when purchased. Without the opportunity to engage in modern and interesting experiments, children come to regard science as lumps of theoretical gristle that seem to have little connection with reality.

Science theory and science experiment are part of the same fabric, so when children realize that to experiment is fun, their understanding of science will develop; in a proportion of students this will be accompanied by a growing science intuition. Experiment thus plays a crucial part in science teaching, but schools need access to appropriate equipment and if expense or other factors are barriers to the provision of suitable materials, alternative ways to run science experiments must be found.

One of the most promising approaches is to use the Internet.

At first, though the Internet was intriguing and novel, it was slow and one-dimensional. Its development into an interactive medium that children understand, enjoy and feel comfortable with has been dramatic. The web already permits sophisticated interaction between a user and a remote computer and it is a logical extension to arrange that a user, when they open a web browser, can connect not to a computer, but to a piece of equipment instead.

This is the realm of the remote experiment. A remote experiment is neither a simulation of an experiment, nor a storehouse of data from an experiment run by someone else, but a real experiment that can be run on real equipment. Accessible via the web, the physical location of the equipment is unimportant, so students anywhere in the UK might access equipment situated in Stockport or Toronto, Exeter or Mumbai.

Advantages of remote experiments

It might seem strange to propose one should run an experiment on equipment located thousands of miles away, but remote experiments offer many potential advantages:

The range of experiments available to students may be greatly increased: all that is required locally is a web-enabled computer and access to the Internet, opening a window on dozens or hundreds of experiments.

It may be possible to access equipment that could never be provided locally: no school could expect to be able to use an electron microscope in the school laboratory, or get time on a geostationary satellite, but these might be available through the web.

Experiments can be run at any time: an experiment does not become inaccessible just because the school laboratory has closed its doors. Learning can extend past the end of class into the lunch hour or after school; students can continue to do experiments and learn at home.

An experiment run through the Internet may not seem like science: this is a crucial advantage. Science has a modest public relations image compared to more sexy topics such as media studies; school science teachers may struggle to make science seem 'cool'. Science experiments conducted through the internet can be fun though; indeed students may not think of such experiments as science at all, so the stigma of being identified as a geek who enjoys science, present in some schools, evaporates.

Collaborative experiments that involve students from different classes and schools, even on different continents, become possible: collaboration among students and institutions in different countries is a major aim of EU education support, so this provides a possible mechanism to fund the development and promotion of Internet-based experiments.

Remote experiments show particular promise in third-world countries: in such countries computers are often cheap and surprisingly widespread in the education system. By contrast, scientific equipment is expensive and therefore a low priority in the school budget. Where the science education of students is book-based, not experiment-based, remote experiments can fill the gap by offering a range of relevant activities.

Remote experiments can support in-service teacher training: many science teachers teach a topic outside their primary area of expertise. Remote experiments offer an opportunity for them to study in greater depth techniques such as nuclear magnetic resonance, which they may include in their lessons, but of which they have only limited first-hand experience.

Challenges in developing remote experiments

If remote experiments have so much to recommend them, surely the Internet should be awash with them? The advantages mentioned above have not been overstated, but significant challenges do exist.

The start-up cost of any experiment must be met: costs fall upon the initial developer of the experiment and may be too great for a school to absorb if it would like to place an experiment on the web.

Commercial software for connecting instruments to the web is generally difficult to use and may be vulnerable to security attacks: there is a need to develop simpler, secure software.

Those placing equipment on the web need an understanding both of computing and of science: programming skills are required to interface equipment with the web, while an appreciation of science is needed so that experiments are scientifically accurate and are not mere entertainment.

So what should be done?

A sound understanding of science encompasses both theory and its application. The truly hands-on experience, when the student performs an experiment locally, is almost always preferable to a remote experiment. But where the Internet can be used to expand the curriculum and provide opportunities for students that would not otherwise be available, it should be used. We should aim to produce a range of experiments through which children can enhance their understanding and enjoyment of science. Remote experiments, just like those performed locally, should be fun, so that, in enhancing their scientific knowledge, children also discover the excitement of science.

An opportunity exists for the UK to take the lead in this emerging area. A small number of school, university, or museum-based centres should be funded to offer remote experiments. Serving the needs of children across a range of ages, these experiments should be sufficiently unusual, expensive, or hard to set up that they would not normally be found in the school laboratory. They should be designed with the needs not only of students in the UK in mind but also those in less advanced countries. Finally, software should be developed that is sufficiently simple and robust that it can be used by a teacher with only an average understanding of computing to connect local equipment to the Internet.

This is one of those rare areas in education in which the potential is great, but the field is only just opening up (and the dead hand of government regulation has yet to weigh down). Substantial gains in our children's understanding of science are possible through the promotion of Internet-based experiments; we should grasp the opportunity.

The following points were raised during discussion:

The schools telescope project is grossly underestimated; six schools use it, but there is no follow-up research concerning its effectiveness on young people. The Science Museum has experimental data on the impact of science learning on children and a website with a large number of visitors and deals with children and adults together. Access to mobile and properly resourced science teaching can be provided through 'lab on a lorry'. Many of the examples of work presented were teaching people how to be project managers rather than scientists. Unfortunately a lot of science is no longer hands-on science in schools for safety reasons which cannot be avoided. However, it is important that students have the opportunity to do things in school which are somewhat dangerous so that they learn to evaluate risk. The effect of safety legislation has been to take out the more dangerous aspects of school science which is a pity. Tracking the benefits of primary school training through to secondary school outcomes is a ten-year project and funding councils will only fund a three-year project. Major government support is required although many projects are locally based and are designed to support teachers who also need inspiration. For most scientists, curiosity is an insatiable driving need which inspires their work. Projects like Awesome Athletes can really stimulate that sort of curiosity. It shows directly that asking questions and finding out the answers is fun, interesting and important. Creativity, in terms of approach and application, can give children freedom to explore and the confidence to realise that there isn't a single right answer.