Practical work in science – Why do we do it? What's it like when it works well?

Professor Sir John Holman

Report on a keynote lecture and workshop, ASE's Annual Conference International Day, 6 January 2016

Professor Sir John Holman (University of York, UK) explained that the aims of the Gatsby Foundation's Good Practical Science project are to compare how nations which perform well in science education use practical work. The result will enable Gatsby to produce a better global definition of the purposes of practical science, could help UK schools to judge how well they measure up internationally, and will lead to policy recommendations. The project started with a literature review, followed by a survey of 11 countries to identify their purposes for doing practical science. It has continued with visits to six of those countries: The Netherlands, USA (Massachusetts), Singapore, Australia (Victoria), Finland and Germany. A final report will be produced during 2017.

From experience and from a study of the literature, Gatsby developed the following list of 5 purposes of practical science:

1. to teach the principles of scientific inquiry;
2. to improve understanding of theory through practical experience;
3. to teach specific practical skills, such as measurement and observation, that may be useful in future study or employment;
4. to motivate and engage students;
5. to develop higher level skills and attributes such as communication, teamwork and perseverance.

Experts in each of the 11 countries we surveyed were asked which of these purposes were prioritised by teachers compared to their governments. The results suggest that:

- teachers tend to rate the motivational purpose of practical science more highly;
- they tend to rate less highly the use of practical science to teach the principles of scientific enquiry and specific practical skills;
- in reality, what is intended to be scientific inquiry may end up as following a list of instructions.

Early findings from the study suggest that:

- there are weighty expectations on practical science;
- the five broad purposes of practical work in science initially identified are widely agreed internationally;
- teachers are not always clear about which purpose they are aiming at with a particular piece of practical work;
- practical work is most effective when it is carefully planned and followed up, and when students have an opportunity to discuss and reflect on results;
- assessment can have a powerful influence on the way practical science is carried out;
- time is also a critical factor;
- in many countries, open-ended practical science investigations are seen as the pinnacle of quality.

Inputs from guest speakers and delegates during the session including:

- Dr Pam Hanley (Institute for Effective Education, University of York, UK)
- Anna Walshe (National Council for Curriculum and Assessment, Republic of Ireland)
- Professor Harrie Eijkelhof (Freudenthal Institute for Science and Mathematics Education, Utrecht University, the Netherlands)
- Dr Hannah Sevian (Associate Professor of Chemistry, University of Massachusetts, Boston, USA)

Dr Pam Hanley (Institute for Effective Education, University of York, UK) presented results from an international review of literature including: comparisons of practical work in different countries; the various purposes of practical work as exemplified in national curricula; and reliable studies of what makes good practical work. It was found that:

- most top PISA 2012 countries include elements of all 5 over-arching purposes, particularly: creating more engaged and conscientious citizens and cultivating particular character traits; and practical skills eg measurement, observation (especially Shanghai-China);
- there are few rigorous studies defining purpose of practical work clearly or measuring it robustly;
- there is more evidence for practical work developing technical/practical skills, and least for societal impact;
- practical approaches based on participation, discussion and reflection show most promise for developing knowledge and understanding;
- there is a lack of international comparisons (3 countries maximum);
- there is little justification for a more in-depth and systematic review.

Anna Walshe (National Council for Curriculum and Assessment, Republic of Ireland) presented on the changing role of assessment in practical science in Ireland. Specifications have been revised as learning outcomes with embedded key skills. From 2016, junior cycle (lower second level), will include classroom-based assessment of practical science. At senior cycle (upper second level), biology, physics and chemistry specifications have recently been reviewed. It is proposed to include an externally assessed practical examination. The assessment of practical science as part of the Leaving Certificate examination is due to be trialled extensively prior to its implementation. As well as carrying out practical activities

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throughout the year, each student must also carry out and report on an extended experimental investigation, which is not externally assessed. The date of the implementation of the revised science subjects has not been decided - it is somewhat dependant on the outcome of the trial.

Ireland have chosen to assess practical science because this will: promote the status of practical work and of scientific practices; allow for significant change in the written assessment; and reward skills that the written paper cannot. However, this decision followed a great deal of work with schools, practitioners, science researchers and policy makers to identify the logistical problems associated with the assessment of practical science, and to develop, with teachers, a variety of different practical assessment tasks and supporting resources. All second level schools (approx. 700) were invited to participate, with 213 applying to join the project and 12 chosen based on school type (Gaelscoileanna; rural; urban; community and comprehensive; VEC; Voluntary secondary; private).

The final model of assessment agreed was that students would undertake a 90-minute practical assessment that is a combination of direct and indirect assessment. Students carry out a series of short tasks based on the specified practical activities, and are are observed by an external examiner who will award 60 marks (15%) directly for skills such as assembling apparatus, working safely and efficiently, following instructions, making accurate measurements and recording data correctly. A further 60 marks (15%) is available for the indirect assessment of the tasks.

Professor Harrie Eijkelhof (Freudenthal Institute for Science and Mathematics Education, Utrecht University, the Netherlands) described the context of practical work in Dutch schools, where many schools are well equipped with laboratories and lab assistants, and where practicals are part of school examination requirements. One particularly interesting feature of school education in the Netherlands is the research assignment, or profielwerkstuk. This assignment forms part of the examination requirements in forms 5/6 (upper secondary school), and is related to 'profiles' which each contain – beside compulsory subjects - a set of related subjects in the student's curriculum, such as Nature and Technology (math, phys, chem + one option), Nature and Health (math, chem, bio +one option), Economy and Society, and Culture and Society. The research may be practical and/or theoretical, and undertaken individually or in pairs (80 hours per person) while supervised by teachers and technicians.

Some support is offered students by universities and research institutes during their profielwerkstuk, including: training students in writing a research proposal; training teachers to supervise students' research; research advice to individual students; and facilities for students' work. The assignment is increasingly considered as the final stage of an investigative learning progression throughout their school career, and commonly involves presentations at school for families. The assignment offers students the opportunity to investigate what they find interesting, encourages bridges between school education and the world of research, and stimulates schools to develop a coherent learning progression in research skills.

Dr Hannah Sevian (Associate Professor of Chemistry, University of Massachusetts, Boston, USA) described the situation in Massachusetts where schools have a great deal of autonomy, and where there are many different layers of influence and perspectives on practical science. Massachusetts has relatively high levels of expenditure on education when compared to other states, and good graduation rates, though this correlates strongly with family income level. High performing schools generally have more science teachers, better and more facilities and equipment, and offer more science options at different levels to their students.

A recent study has examined how various factors intersect to shape school decisions about their science curriculum and teaching, but particularly how national reforms are implemented and influenced in local-control policy environments. Emerging results suggest that the main levers for implementation are:

- a link to assessment;
- the realisation of common values/goals;
- aligning with or building on current efforts;
- the opportunity for change or to empower educators;
- the availability of resources and professional development.

However these levers can become destructive if:

- assessment is made difficult due to changes in standards, timing of development, and resources;
- realization of common values/goals is constrained by lack of leadership, buy-in, and resources;
- messaging is not consistent, or it is not clear how multiple initiatives work together;
- science accountability at elementary and middle school is not seen as an opportunity.

46 delegates from the following countries then joined a workshop to discuss the points made in the lecture: Australia; Bermuda; China; Iceland; Indonesia; Ireland; Japan; Lithuania; Netherlands; Norway; Scotland; South Korea; Spain (British education system); UK; Uruguay; USA.

Workshop attendees were asked to reflect on which of the 5 purposes for practical work presented in the previous lecture were considered most important in their country.

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While most attendees were from the UK, across all countries the purpose most frequently considered most important was that of teaching scientific enquiry (27%). Comments testified to scientific enquiry being a way to learn about scientific method 'by doing', and that this is key for understanding scientific evidence (UK). However, one UK attendee noted that practical work to teach scientific enquiry was often more of an intention than a reality, not helped by large class sizes.

One attendee noted that, in order for students to conduct successful scientific enquiries, they need to have gained the necessary practical skills first. So while the purpose of practical work to teach scientific enquiry wasn't much more important than that of teaching specific practical skills, it was rather dependent on it having happened. Also noted was that these two purposes may not be compatible in a single practical activity – teaching a specific skill might be best done through following instructions, which is not conducive to an enquiry approach. And to use these practical skills at secondary level relies on them being built during primary school – leave it too late and older students can struggle with their practical work (South Korea).

17% of responses supported practical work as most important for teaching the understanding of theory, with the suggestion that this was particularly useful with theories which are difficult (UK), and enabled learning to become "real not rote", with students exploring facts themselves and internalising their learning more effectively. Representatives from the UK seemed to most value the purpose of motivating and engaging students through practical work, but this seemed to work in different ways – very simply as a tool for getting students' attention and for breaking up content-heavy sessions and long days, but also to encourage future aspirations towards science. One person commented that successfully gaining a practical skill is motivating in itself for many students – a reminder that these purposes can co-exist.

The value of practical work in motivating and inspiring teachers (as well as students) was mentioned a few times. But other, related purposes were cited during discussions – that of affording an opportunity for students to offer up their own views on science (South Korea), of utilising skills and knowledge from other subjects (eg maths, reading), of facilitating creativity, self-reflection and independence, and of giving the opportunity of learning in unfamiliar environments eg. through fieldwork.

When asked what enables good practical work in their countries, attendees had some very similar responses. Sufficient teacher time was paramount - to plan a good lesson that links practical with theory, but also to stop and reconsider whether traditional practicals were actually of most value. Time – and education/training - was also implicit in the need for teachers being confident and skilled in the use of practical work, but also genuinely believing in its value. However, time was less of an issue in countries which had school science technicians, who could not only suggest and prepare for practical activities, but could mentor under confident teachers through the process. In these countries, they could cope with larger class sizes in the lab than in those (eg Iceland) where technicians were absent.

Another key theme was that of support – support from anyone who had the power to influence class sizes, budget, curriculum, assessment, and teacher freedoms. This may be a local authority (US), or a headteacher (UK) or an assessment regime (Indonesia, US) or curriculum, particularly in terms of there being time and space for students to think, trial, make mistakes, discuss, and improve their practical work (UK). Money was mentioned directly (Iceland, UK), but also indirectly in terms of resources (Australia, Lithuania, Norway).

A number of attendees mentioned that good practical work in Primary school enabled good practical work in Secondary science (New Zealand). Clear curriculum expectations and an inspection regime which prioritised practical work was important in China. In the Netherlands, links with universities who 'opened their doors' to keen students enabled the 'gold standard' of practical work – the extended investigation – to thrive. A similar comment was made by UK teachers – that enabling some students to participate in real, cutting-edge science, as well as giving all students equal opportunities to benefit from its many purposes, was what made practical work in their country good.

In summary then, across all the countries represented there were many purposes for practical work and these all interacted, some very positively and some less so. Similarly, the factors enabling good practical work in one country or context could inhibit it elsewhere. The undeniable enabler, though, is the teacher who has the time, skill, belief and confidence to choose the right practical for the right purpose, and who is as unconstrained as possible in their choice of that activity in terms of the resources and support available. Of course, few of us live in such an ideal world, and it remains a challenge to disentangle good practice from coping strategies.