Field studies for key stage 4 on mine water pollution: a university and museum collaboration

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ABSTRACT This article describes how a university and a museum have worked together to create a 'How science works' workshop entitled 'What's in our water?' The workshop teaches students about the continuing pollution from a disused coal mine, how the pollution is cleaned up using a state-of-the-art treatment works and how scientists monitor the site. The article also discusses how and why the workshop was developed, the science of acid minewater drainage and the strengths and weaknesses of outreach events of this nature.

The University of Huddersfield and the National Coal Mining Museum for England first came together in 2006 to discuss running a workshop on applied science for key stage 4 (ages 14–16) students. The aim was to develop an activity based on the water-treatment works that are sited at the Museum.

Both institutions have since collaborated to produce a one-day science event entitled 'What's in our water?', in which students collect and analyse water samples taken from different stages of the minewater-treatment process. The event, which includes a tour of the former underground mine workings, is delivered over a one-week period in autumn and over a two-week period in summer.

From 2007 to 2012, a total of 41 events were delivered to 21 schools, with class sizes ranging from 15 to 35, reaching over 1000 key stage 3 (ages 11–14) and key stage 4 students (ages 13–16).

This article describes the event and discusses the nature of the university and museum collaboration.

The mine

Hope Pit and Caphouse Colliery (Figure 1) are two former collieries that are now part of the National Coal Mining Museum for England. They are in open countryside next to the main road between Wakefield and Huddersfield in West Yorkshire. Together they include many miles of underground workings, penetrating to a depth in excess of 150 m. At its peak of productivity in the early 1980s, half a million tonnes of coal were produced per annum (Schofield, 2003). The mine closed in 1985 and its conversion to the Yorkshire Mining Museum started in 1986.

The chemistry

Mining alters the natural rock, and minerals that might previously have been protected from chemical and physical weathering become exposed. The disturbed rock is typically rich in iron sulfide minerals (Johnston *et al*., 2008). The mine receives its fair share of rain, which permeates through the ground and into the underground workings. Dissolved oxygen in the water then reacts with the iron sulfide to produce iron(II) sulfate and sulfuric acid:

Figure 1 The headgear at Caphouse Colliery

$$2FeS_2(s) + 7O_2(g) + 2H_2O(l) \rightarrow 2FeSO_4(aq) + 2H_2SO_4(aq) \quad \text{(reaction 1)}$$
iron(II) sulfate

Iron(II) sulfate, also known as ferrous sulfate (the main component of over-the-counter iron supplements), is pale green in colour.

A second reaction then takes place in which the soluble iron(II) sulfate is oxidised to an insoluble, bright-orange iron(III) hydroxide. This is called ochre or yellow boy. Sulfuric acid is also produced:

$$4FeSO_4(aq) + O_2(g) + 10H_2O(l) \rightarrow 4Fe(OH)_3(s) + 4H_2SO_4(aq) \quad \text{(reaction 2)}$$
ochre

The pH can be less than 2.0, hence the name acid mine drainage (AMD). However, the final acidity is dependent on the concentration of dissolved carbonate in the ground water, which is dependent on how much carbonate is present in the local soils and rocks. In the case of Hope Pit, the pH is between 6.5 and 7.0. The neutralisation reaction is:

$$2NaHCO_3 + H_2SO_4 \rightarrow 2CO_2 + Na_2SO_4 + 2H_2O \quad \text{(reaction 3)}$$

Without intervention, the water that passes through the mine would cause the workings to flood, releasing orange water onto the surrounding farmland. Moreover, the longer the water stays in the mine, the more acidic it becomes and ions of lead, arsenic and mercury may start to accumulate.

The event

When facilitating the event for schools, the entire day is spent on-site at the museum. After an introductory talk, schools spend most of their time analysing the water, divided between work carried out in the field and tests done in a laboratory setting.

The field and laboratory work takes just over two hours and is carried out in the morning. The afternoon is taken up with the underground tour of the former mine workings at Caphouse Colliery. A typical timetable is:

9:45	Arrival
10:00	Introductory talk
10:25	Tour of treatment works, gathering samples, performing fieldwork
11:45	Break
12:00	Laboratory session
13:00	Lunch
13.50	Underground tours
15.10	Departure

For the laboratory session, one of the museum's education spaces is used, with the help of equipment loaned by the university alongside items purchased especially for facilitating the event.

The treatment works (the tour)

The treatment works are spread over 0.035 km^2 (approximately 9 acres) of museum land. It comprises a pumping station, a weir, a series of settling ponds (that look like swimming pools) and two large reed beds. The average volume of water pumped out of the mine is 2000 m^3 per day (Foster, 2005), which is equivalent to the volume of about five 25 m swimming pools.

The tour of the treatment works takes just over one hour and includes sample collection, measurements of dissolved oxygen, temperature and turbidity (cloudiness) and explanations of the different processes. The field measurements are taken in triplicate. The pH and iron concentration are measured back in the laboratory. All the measurements are taken by the students.

Equipment used on the tour (based on a class size of 30) includes:

- oxygen probes and meters (4);
- sodium sulfite solution (2 g in 100 cm^3) (1);
- temperature probes and meters (3);
- turbidity meter (1);
- 2.5 dm^3 plastic carboys with taps (5).

The tour begins with a walk to the pumping station to collect the first sample (A). The water is colourless, slightly acidic (pH 6.5) and the

Figure 2 The weir at the treatment works, showing the transformation of colourless Fe(II)-rich minewater into orange deposits of $Fe(OH)_3$ (also referred to as ochre or yellow boy)

concentration of dissolved oxygen is low (45%). Most of the iron is present as Fe^{2+}(aq); however, the concentration is too dilute for the pale green colour to be observed. The water chemistry is best defined by reaction 1.

The students are then shown the weir (Figure 2), the design of which greatly increases the concentration of dissolved oxygen to 90%, and causes the oxidation of Fe^{2+} to Fe^{3+}. Colourless water enters the weir and becomes bright orange. This colour change corresponds to reaction 2.

The orange water passes into a series of settling ponds in which most of the particulate

Figure 3 Two of the settling ponds

Figure 4 Students of Batley Business and Enterprise College observing orange water at the reed bed inlet (sample B)

Figure 5 One of the two reed beds, each having an area of 2000 m^2 (0.5 acres)

iron(III) hydroxide settles out (Figure 3). The second sample (B) is taken from the outlet of these ponds, at the inlet to the reed beds (Figure 4). The remaining iron(III) hydroxide is then removed through the filtering action of two large reed beds (Figure 5). The third sample (C) is taken half way along at the edge of the first reed bed.

The fourth sample (D) is taken from the reed-bed outlet into the stream and the fifth sample (E) is 50 m downstream. The stream eventually joins the River Calder. The combined effect of the settling ponds and reed beds is to reduce the total iron concentration in the minewater from 30 mg dm^{-3} to 2 mg dm^{-3}.

Monitoring of the minewater is carried out on a weekly basis by the analytical science company, Environmental Scientifics Group (ESG). The tests used by students in the 'What's in our water?' laboratory session are similar to those used by ESG. There is a legal limit set by the Environment Agency for discharges of iron, but the museum has undertaken to keep to a lower limit of 3 mg dm^{-3}.

The laboratory session

In the laboratory, students work in groups of two or three (Figure 6). Each group has to determine the total concentration of iron and the pH for each of

Figure 6 Students of Kettlethorpe High School, Wakefield, analysing and recording total iron concentration

the five samples, A–E. They then have to present the data in the form of bar charts and line graphs.

Equipment used in the laboratory session includes:

- pH electrodes and meters (6);
- pH 7 buffer solution (2);
- pH 4 buffer solution (2);
- safety gloves. S, M and L (1 box of each size);
- Hach FerroVer® reagent powder sachets (50);
- 100 cm^3 polyethylene sample bottles (50);
- stopwatch (10);
- 25 cm^3 measuring cylinder (10);
- tall 25 cm^3 glass sample tubes and lids (50);
- deionised water wash bottles (10).

The standard method for measuring the total concentration of iron (Fe^{2+} + Fe^{3+}) in the laboratory is to use a solution of 1,10-phenanthroline containing a reducing agent. Any Fe^{3+} is converted to Fe^{2+} and the total Fe^{2+} then forms a bright orange complex with the 1,10-phenanthroline (Figure 7). The deeper the orange colour, the greater the absorbance of light and the higher the concentration of total iron. Environmental scientists use dry-powder mixes of 1,10-phenanthroline and reducing agent as these can readily be mixed with samples in the field. The aim is to simulate the work of an environmental scientist and, therefore, FeroVer® iron reagent powder pillows purchased from Hach are used (one pack of 100 sachets costs approximately £25). The students estimate the concentration of total iron using a colour chart.

The pH values of the solutions are determined using pH electrodes. A typical set of results is shown in Table 1 and Figure 8.

The underground tour

The underground tour of the former workings at Caphouse Colliery is enjoyed by many visitors to the museum (Figure 9). The tour, which lasts a little over an hour, goes through former workings that the museum has displayed and arranged to imitate historic working environments and practices, and follows a chronological route from the early 19th century through to the closure of Caphouse in the mid-1980s. The tour is delivered

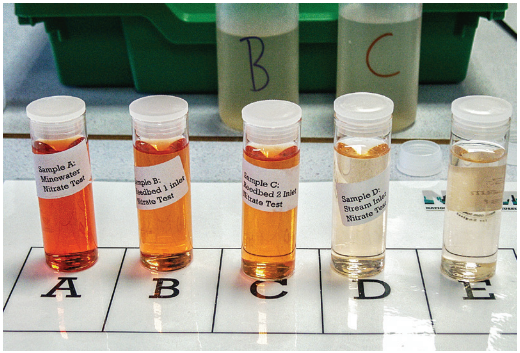

Figure 7 Diluted samples of minewater containing 1,10-phenanthroline

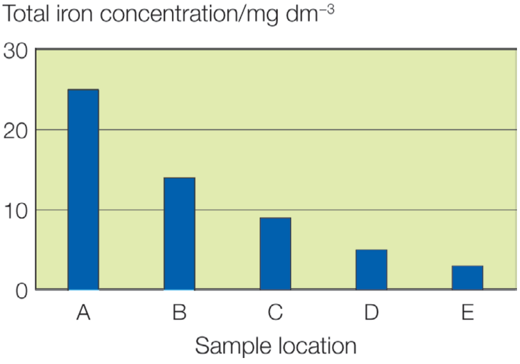

Figure 8 A bar chart showing the concentration of total iron at the five different locations (sample A is untreated minewater and sample E is treated water as it leaves the Museum land); data taken by King James's School, Huddersfield, 19 September 2007

Table 1 Average field and laboratory results taken by students of King James's School, Huddersfield, on 19 September 2007

	Sample				
	A	B	C	D	E
Temperature/°C	15.0	13.6	13.3	13.2	13.8
Dissolved oxygen/%	43	89	93	97	99
Turbidity/TU	26	125	75	40	38
pH	6.90	7.80	7.80	8.00	8.00
Total iron/mg dm^{-3}	25	14	9	5	3

Figure 9 Students of Kettlethorpe High School, Wakefield, going down the pit

by former mineworkers and takes place at a depth of 140 m below the surface, through workings used when Caphouse was exploiting the New Hards Seam. Most schools that visit the museum opt to take the tour and it is felt by many teachers that the tour puts their curriculum-linked work into context.

New Science GCSE – structure, content and 'audience'

In 2006, there were changes to the key stage 4 science curriculum in England and Wales, which put a greater emphasis on the knowledge, skills and understanding of how science works in the world at large as well as in the laboratory. The new section of the science curriculum entitled 'How science works' encourages students to plan and carry out practical work, collect their own data and consider the applications and implications of science.

OCR described their Applied Science GCSE (national exam for 16+ students in England and Wales) thus:

GCSE in Applied Science (Double Award) is one of a number of GCSEs in vocational subjects designed to offer students the opportunity to widen their participation in vocationally related learning. The course provides students with the technical knowledge, skills and understanding needed in the workplace, in further education or training. (OCR, 2005)

It goes on to say:

Students with this qualification could progress to areas of employment as medical technicians, pharmaceutical technicians, work in industry, the service sector or education.

The museum's educational remit

The Museums Association defines a museum by saying '*museums enable people to explore collections for inspiration, learning and* *enjoyment*' (Museums Association, 2008). Intrinsic to this definition is learning and education. The National Coal Mining Museum for England has a very strong educational remit and attracted 17 290 school children in the 2011–2012 period. The requirements of these school visits can vary according to age, key stage, subject, topic, and so on.

The majority of school visits are from primary schools and this is for two main reasons: first, there is less pressure on the timetables in key stages 1 and 2 (ages 5–11) than in key stages 3 and 4 and, second, the level of subject-specialist knowledge required by museum educators to facilitate curriculum-relevant sessions is much greater for key stages 3 and 4. Subject areas covered by existing workshops and sessions include history, science, geography, literacy, citizenship, design and technology and art.

The university's remit for outreach work

The university's outreach programme has three main strands: first, to raise awareness of the university and its courses; second, to encourage enquiries and applications from potential students; and, third, to promote widening participation by raising the awareness, aspirations and attainment of young people from under-represented groups.

Outreach can be defined as subject- or non-subject-specific. Subject-specific outreach is delivered by academics from the different subject areas. Non-subject-specific outreach is delivered by the schools liaison department.

The Department of Chemical and Biological Sciences delivered subject-specific events to 430 young people in the 2011–2012 school year. The types of event include competitions, taster days, e-mentoring, curriculum support, work shadowing, workshops and splash events such as the 'DNA World Record' (University of Huddersfield, 2008). The majority of events are targeted at key stage 4 and sixth-form students. The primary school work is mostly undertaken by the schools liaison team.

Considerable effort goes into the design of the subject-specific events so that they reflect the department's commitment to teaching and learning. The events also provide an opportunity for university student volunteers to gain experience of working with young people, especially if they are considering a career in teaching.

Schools' expectations of external providers

Schools are often unaware that there is a wide range of subjects offered by external providers and that their products are increasingly linked to the National Curriculum, the QCA Schemes of Work and exam syllabuses.

Liz Morton, Head of Chemistry at Queen Margaret's School, York, commented:

The decision to visit the National Coal Mining Museum was made after a visit by a colleague and myself three months prior to the event. We had been looking at our planning for the summer term and felt that we needed to enrich the curriculum content by letting our students see the chemistry we were discussing in school in the field situation. We wanted a venue that was reasonably accessible and one that would complement the teaching we had already carried out. We had been studying rocks and looking at the industrial uses of locally mined coal and limestone. We had extended our work on limestone into the making and testing of concrete slabs in the laboratory: the essential 'How science works'!

The workshop 'What's in our water?' was an excellent find. The chemistry content was pitched exactly right; there were questions to stretch our more able students but it was accessible to the whole group. It was very interactive and, despite our group being the maximum size, all students took readings in the field and worked in small groups in the classroom.

The university and museum collaboration

The purpose of the collaboration was to bring together the scientific knowledge of the university with the opportunities offered by the unique site of the museum.

The university's School of Applied Sciences has well-equipped modern laboratories and delivers BSc and MSc degree programmes in Accelerator Science, Biological Sciences, Chemistry, Forensics, Nutrition and Pharmacy. A number of the academic staff are experts in environmental science, and environmental chemistry together with fieldwork is taught as part of the foundation science degree. The university was, therefore, able to lend its environmental testing kits along with all the glassware and chemicals. The university also provided the necessary expertise to undertake meaningful sampling of the minewater-treatment facility and to interpret the results.

The National Coal Mining Museum for England, like most museums, has an education team, which is made up of teachers and museum-education specialists. The team keep abreast of developments in the National Curriculum and in current teaching theory and practices, and this enables them to maintain content and resources that are relevant to visiting schools. The museum frequently makes use of focus groups made up of practising teachers to help inform the development of workshops, sessions and other educational resources.

The university and the museum are 8 miles apart and this close proximity has a number of benefits. First, it has been easy to schedule meetings and so contact time between the two organisations has been good. Second, the schools that are local to the museum are also the ones that are local to the university. This means that both the university and the museum can work together to increase their presence in the local community. The authors have also benefited greatly from sharing good practice.

Development of the event

The event was first run for year 11 students (age 15–16) from King James's School, Huddersfield, who were studying for their General Certificate of Secondary Education in Environmental Science and needed material for their coursework. It was then decided to make the session more relevant to the key stage 4 science curriculum.

A teacher-consultation evening was arranged in which the exam syllabus requirements, the practicalities of organising a visit, pre-visit support materials and potential barriers to taking part in the session were discussed. The event was also discussed with Mark Storey from Wakefield Local Education Authority.

Some of the conclusions were:

- the idea of doing real science was very attractive;
- the session needed to be linked specifically to exam syllabuses for key stage 4;
- there would be scope for the session to provide direct support to a unit of work in GCSE Applied Science called Developing Scientific Skills;
- the session would have to incorporate scientific terms and vocabulary as outlined in the syllabuses;
- teachers would need to be able to plan the day closely with the museum staff so that it would fit the requirements of their students;
- the session would be appropriate as an enrichment activity for key stage 3 students;
- the session would need to be available for a whole year group if the visit was going to be embedded into a scheme of work;
- pre-visit information is very important.

Two versions of the 'What's in our water?' event were developed. The first was marketed to science teachers as a session that would directly support GCSE Applied Science coursework (Developing Scientific Skills) and would allow assessment in the following skill areas:

- planning and following instructions;
- obtaining evidence by experimenting;
- analysing and considering evidence;
- evaluating evidence;
- vocational application.

The second was promoted to Gifted and Talented Coordinators as an enrichment session in science. The learning outcomes for gifted and talented students focused more on building skills and offering a unique experience of science:

- to experience real science set in a vocational context;
- to develop an understanding of the skills required by scientists in the work they undertake;
- to develop practical skills and use chemical-analysis techniques;
- to stimulate and enthuse students about science;
- to understand the impact of mining on the local environment;
- to understand how the water-treatment plant at the museum works.

Results from student feedback forms

Some of the events in 2008 were evaluated using simple feedback forms. The results from a selection of questions are shown in Tables 2–6. The sample size was 120.

Discussion

Less than 40 years ago the National Coal Mining Museum for England was a busy, noisy industrial site at which teams of men would work in shifts throughout a 24-hour period. The impression one gets today is very different. Birch trees grow on the spoil tips and a stream winds its way alongside a nature trail. The one attribute that has not changed is the discharge of orange water, which serves as a useful reminder of the previous life of the colliery site.

For the students, the investigation of the treatment works helps to put science into context and is the real strength of the 'What's in our water' event. The chemical tests that the students undertake for iron, pH, temperature, oxygen and turbidity are the same as those done by real scientists, working for analytical science companies, who regularly monitor the discharge water. The students can also see for themselves how a mine might continue to affect the environment long after closure and how the problems can be overcome in an environmentally sustainable manner. Moreover, the event introduces the students to one such environmentally sustainable strategy, which is the use of reed beds to clean the water. The use of specialist equipment such as pH electrodes and oxygen probes also adds an extra interest factor to the event. The data that each student collects have to be represented in graphical form, either as a bar chart or a line graph, which helps the students to practise graph drawing for continuous and discontinuous variables.

Table 2 How did you view the day on the whole?

Not enjoyable (%)	Disappointing (%)	OK (%)	Enjoyable (%)	Fantastic (%)
0	4	20	69	8

Table 3 Which of the following words would you use to describe the day? You can give more than one response.

Word	Number of responses
Interesting	63
Informative	52
Fun	50
Challenging	22
Creative	22
Hard work	18
Inspiring	16
Surprising	15
Fulfilling	6
Boring	6
Intense	5
Irrelevant	1

Table 4 Please list your favourite three subjects at school.

Responses that included science = 40%
Responses that did not include science = 60%

For the teachers, the event helps to tick boxes in their curriculum planning and the work booklets can be used for coursework. The workshop reinforces investigative skills that are required for GCSE practical science.

From the museum's perspective, the session is a positive experience, not only because it attracts a willing audience whose act of visiting contributes in a number of positive ways to the museum, but also because a part of the site, the museum's collections and the history of mining are interpreted in an interactive and inspiring way. Science can often be a difficult subject to deliver successfully in a museum environment where the museum's collections and the curriculum have no obvious overlap.

Table 5 How do you feel about science in general?

Totally uninterested (%)	Not interesting (%)	OK (%)	Interested (%)	Really interested (%)
1	4	31	42	22

Table 6 How do you feel about science at school?

Really do not like (%)	Do not like (%)	Do not mind (%)	Like (%)	Really enjoy (%)
3	3	26	50	19

BOX 1 Safety notes

- The workshop described in this article, and all activities involved, have been fully risk assessed by the museum and university staff. Students are supervised at all times and, in the laboratory work, suitable personal protective equipment, including lab coats, protective eyewear and gloves, is provided. Careful instructions, both written and verbal, are given regarding all the testing procedures.
- Care should always be taken when working near open bodies of water. Many of the lagoons and settling ponds at the museum's minewater-treatment facility are surrounded by high fences and are only accessible by authorised staff for maintenance and monitoring purposes. Samples are therefore only taken from areas that are accessible to the general public. The act of taking the sample is only done by members of the museum or university staff, and students are always supervised by their own teaching staff and by staff from the museum when in these areas.
- Caution should be exercised when working with samples of water taken from outdoor settings. Staff and students are advised that the pollutants that are the subject of this investigation are not toxic in themselves, but that the water may contain other chemicals or sources of potential infection such as Weil's disease. The first precaution is to prevent the water from coming into contact with the skin, and gloves are worn throughout the laboratory session. Additionally, staff and students are all advised to wash hands thoroughly at the end of the workshop and especially before eating.
- The FerroVer® reagent used in the laboratory session carries a HARMFUL warning label, and the safety data sheet is available from the Hach website (2012) with the product code 85499. Students are supervised while using the reagent and wear appropriate personal protective equipment including goggles and gloves.

Although there are many positive aspects to the workshop there are also some challenges. One is that the science workshop is expensive. The workshop requires at least two staff per class, who are responsible for preparing the materials, teaching, tidying up and administration. The iron-analysis sachets also need to be purchased and equipment such as the oxygen probes needs to be purchased and maintained. To date, these costs have been mostly met by the university and the museum. Some visiting groups are more motivated than others, the most highly motivated comprising those students who have been introduced to the topic of minewater pollution before attending the workshop. Students attending the workshops who are with their own teacher and classmates also perform well. Students who are prepared for the visit tend to be more receptive and engaged with the sessions.

The university's experience of running workshops, as evidenced from feedback forms, is that students prefer an emphasis on fun. These are the so-called 'whizz-bang workshops', an example of which is making shampoos. Students can engage with shampoos because they are very familiar with them. They enjoy mixing them, adding colour and scent. They do not need much classroom-science ability to participate and it is not curriculum-linked. The 'What's in our water?' workshop is different from this as it is based on curriculum-linked learning objectives and aims to engage students by being relevant to the outside world.

Discussion on the meaning of science in the curriculum

There has been some debate among the authors about the requirements of the National Curriculum and the meaning of science. There is an implication in the syllabus that science is only an investigative process. Students are told that scientists first make hypotheses and then go about systematically testing them. The 'What's in our water?' event does not require prior scientific knowledge, but an application of good scientific practices and methodologies. Students do not need to understand the chemistry of the reagents, or even the process of iron pollution and iron removal, but they need to do the tests in a systematic manner. Science in the UK is as much about analysis as investigation. Most scientists in the UK are employed as analytical scientists rather than investigative scientists.

Initially, the authors were intent on using the language of the syllabus and therefore on creating a workshop with an investigative edge. However, because teachers liked the fact that students were able to mimic the tests done by real analytical scientists on site every week, there was continued debate about whether the session was really an investigation and whether it really needed to be one. Now students are presented with the question 'Does the water treatment process work?'

Conclusion

The 'What's in our water?' event could only have come about through collaboration. The university brought scientific expertise and resources, while the museum was able to contribute a unique working site and a functioning education team that works regularly with schools. Both institutions have greatly benefited from sharing good practice and reaching out to new audiences.

Acknowledgement

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If you are interested in booking the 'What's in our water' activity or visiting the minewater treatment plant at the National Coal Mining Museum of England then either email Stuart or Jayne or phone 01924 848806.