Dilemmas of Science Teaching

Perspectives on problems of practice

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Laboratories

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Editors' introduction

The laboratory is a commonplace of science and school science. For more than a century, the laboratory has been uniquely associated with the pursuit of school science. The science curriculum is infused with images of students conducting rigorous laboratory-based experiments, mimicking the behaviour of real scientists in real scientific laboratories. 'Hands-on' has become a catch cry for science education, particularly over the past forty years, driving curriculum development (and facilities management) in the developed and developing worlds. And yet, notwithstanding the central place of the laboratory in school science, there is a growing corpus of research which calls into question both its value and effectiveness, and its connection to the enterprise of science (Hegarty-Hazel, 1990; Hodson, 1993; Lazarowitz and Tamir, 1994; Milne and Taylor, 1998; Tobin, 1990).

Two major critiques of school science laboratories have emerged in recent times. The first critique draws attention to the mismatch between the high ideals of laboratory-based inquiry and the reality of most 'cookbook' style practical work, with its emphasis on skill development and confirmation of predetermined conclusions (Hodson, 1993). The presumption that the school science laboratory is a place for genuine inquiry is largely a myth (Hodson, 1990; Milne and Taylor, 1998). Much of what goes on under the guise of experimentation is routinised and more concerned with technique and data than discourse. Assessments typically reflect an image of laboratory work as a closed rather than an open-ended enterprise. Genuine experimentation is rare, often confined to extra-curricular science activity such as science fairs. Given this state of affairs, many commentators are now calling for more 'authentic' forms of laboratory work and assessment, emphasising intellectual and problem-solving skills, a much reduced emphasis on technical skill-based bench work (Arzi, 1998) and an expanded definition of the term laboratory to incorporate recent advances in information technology, and data collection and processing.

A second and related critique of laboratory work centres on the assumption that students can mimic in some way what happens in 'real' science laboratories. Many scholars have observed that science in 'real' laboratories is conducted within a social milieu of interpretation, justification and argumentation. Scientific positions are 'constituted by the researchers' paradigmatic affinities which contribute to frame a phenomenon, to define the operating conditions under which its observation is carried out' (Désautels and Larochelle, 1998, p. 118) and to determine how data are to be treated (Woolgar, 1990). These positions are socially derived and argued within particular communities of scholars, in accordance with sets of beliefs, rules and assumptions. By contrast, school students typically act from an individualistic perspective, believing that objects or phenomena offer up observations to the observer, that data speak for themselves, and that observations and data form the basis for theory building or modification (Désautels and Larochelle, 1998). Indeed, in the absence of an interpretative frame, students appear ill equipped to mimic the mature and complex patterns of social behaviour of 'real' scientists.

Taken together, these two critiques – about the mismatch between goals and realities, and about the difference between school science and 'real' science – provide a complex set of issues for teachers and others who wish to reform the school science laboratory. These issues include how to imagine a form of laboratory work which is 'authentic' in a world where students lack the social and cognitive resources to mimic the scientific endeavour, how to move the emphasis from an individualistic view of science towards science as a social practice, and how to shift from a culture of right answers to a culture of interpretation, negotiation and justification. These issues form the backdrop to the story that follows. In Titrations, titrations, Bevan McGuiness recounts his experience in teaching the technique of titration to a group of Grade 11 senior chemistry students. In doing so, he raises questions about the relevance of the activity and the type of learning taking place. The story is followed by his own commentary on the activity and comments by Wolff-Michael Roth and Penny Gilmer.

Titrations, titrations

Bevan McGuiness

Teaching senior chemistry can be a mixed blessing sometimes. There are times when you just have to slog through lengthy theoretical sections, such as atomic theory and electron configurations, where there simply aren’t any easily performed experiments available. And then there are times when there is a whole series of intricate and demanding experiments. Such a time is titration time. It comes along every year at the same stage of the course, when we dust off the
burettes, find the volumetric flasks and introduce the students to the joys of titres, aliquots and equivalence-points.

I remember one year, I had an excellent class. They were motivated, quick to grasp concepts and eager to excel. So naturally when it came time for the titration section, I was keenly anticipating the way in which they would approach their work. In preparation, I found some of my laboratory note-books from my university days and made sure of the intricacies. If any class I had was likely to ever stretch my understanding of a technique, it would be this one. So I practised, I spoke to the laboratory technicians and asked them to check that all the burettes they provided were of the new type with the teflon taps that would not fall out unexpectedly and generally made a nuisance of myself around the laboratory workshop.

In class I prepared the students by directing them to the appropriate sections in their textbooks so that when they came to class they would be well prepared for the experiment. We talked in advance about the idea of experimental uncertainty and how it could be reduced by the use of precise apparatus, and we discussed the difference between accuracy and precision. In all I thought them well prepared for the, what I considered, fun ahead.

At last the day arrived. I remember it clearly. It was warm and sunny, the students came in just after lunch-time and they were all a bit hot and sweaty. Immediately they came in I called their attention to the demonstration titration I had set up. Carefully I went through the steps. I demonstrated the technique that my teacher had shown me when I had been in high school.

First of all, I went through the use of the pipette, showing the manipulation of the two different types of pipette fillers and discussing the reasons for not pipetting by mouth. Then I put the conical flask under the burette and with my right hand swirling the flask, I put my left hand around the burette and carefully opened the tap to allow the low concentration acid dribble out into the swirling flask. It was at this stage that I remembered that I had not put in any indicator, so I played my favourite game of ‘spot the deliberate mistake’ and challenged the students to identify what I had forgotten. It was gratifying to have several students volunteer the correct answer. Carefully, I added the appropriate indicator, demonstrating the technique of adding it to the aliquot of alkali.

It was great, I did three titrations and got them to within 0.5 ml of each other. At the third the students even gave me a little round of applause. We then discussed the use of error analysis to correctly record the results. This last exercise slowed down the interest of the class as the realities of the complexities of percentage errors dawned upon them. By the time all of this had been covered, the period came to an end. I farewelled my class with cheerful cries of ‘See you tomorrow’ and reflected on a very successful demonstration lesson.

The next day when the students started their own titrations I had second thoughts about the success of the demonstration. At the outset, the students made basic errors in their pipetting techniques. Then they insisted on making the actual titration a two-student job, with one swirling the conical flask and the other operating the tap. I watched in disbelief as I walked around the room. Finally I could take it no more, and called them all to stop what they were doing and pay attention to the front of the room. Once again, I went through the whole procedure, demonstrating and explaining as I carried out another titration, and once again, I sent them back to their desks to try the technique. This time they performed a bit better, but still there were errors. Oh, well, there is always tomorrow.

Tomorrow came and the students tried once more to master the technique of titrating. It is worth pointing out at this stage that we were working through a series of experiments. The first was to prepare a standard solution, then to use that to standardise another solution. This standardised solution was then to be used to calculate the concentrations of two or three commercial products. Naturally, a certain amount of time had been allocated to this set of practical work, an amount that is, on paper, quite generous. Of course, it was becoming apparent that this class would run over time. But, as always, I chose to ignore that in preference to finishing the work.

The work continued on the following day, the one following that, and on for several days. During that time, the students’ skills improved and their titrations became more and more accurate, and more precise. Once this had occurred, it was time to discuss error analysis. Typically, this elicited groans of complaint, indeed disbelief when the complexities involved became apparent. This class was no exception, and there came the predictable ‘Oh no’ and ‘You’re kidding’ and even a few ‘I don’t get this at all’ remarks. But, being good students, they buckled down and made the effort to learn the mathematical manipulations necessary to deal with percentage errors and experimental uncertainties.

However, after all these difficulties, we struggled on through together. I say ‘together’ seriously as it felt that I became a part of the class, joining in with their struggle with this long and demanding period of their studies. We had worked hard and we had come to the stage where the titration technique had been successfully tackled and, dare I say it, mastered.

Finally, the time came when we faced the last hurdle, the end of unit test. Somewhat nervously, I collected the test papers from my colleague who had written it. Walking to the class, I read through it and felt comfortable. As tests
went, this was a fair, if predictable, one. There were three nice titration calculations and even a few multiple-choice questions based on titration technique. That pleased me, considering how much work we had put in on the technical side of the course.

However, when I marked the tests, I was shattered. Apart from the predictable few students who would succeed at anything, the marks were very poor. Indeed they were appalling. I couldn’t believe it. Hadn’t we spent more time than normal? Hadn’t I personally spent literally hours going over and over again the whole titration system?

The answer, when it came, should not have been a surprise. I asked one of the mid-range ability students (you know the type, he averaged a C, but on a good day pushed it up to a B, a good lad who tried hard and gave his best) what had happened.

‘What happened, Bill? We spent heaps of time on titrations and you all bombed badly on the test. What’s the story?’ I asked him.

‘Yeah, but we spent all the time on the skills, the experiments. The test was all on calculations about titrations. We all studied up on the techniques, you know, all the stuff you taught us. We didn’t think too much about the calculations’, he said, a little bitterly.

‘But I told you all that the whole thing was about the calculations at the end. I said that’, I protested.

‘Oh yeah, you did. But we spent all that time on the pracs. So we thought that was the big thing’

As he walked away, carrying his test paper with the 29% grade in red on the front page, I was forced to reflect that maybe I did indeed have to think, perhaps re-think, my priorities in teaching chemistry.

Teacher commentary

Bevan McGuinness

Whenever we teach students we take on a wide range of tasks and problems. The task of teaching chemistry is no different in that it has its own peculiar brand of problems. One of the major problem areas that is highlighted in this everyday story of a commonplace event is that of assessment. When we assess students, what exactly are we assessing? And, even more significantly in this story, do our ideas of assessment always coincide with those of our students?

In this story, I had spent a noticeably long time with this particular class going over the practice of the titration analysis technique. Whilst this was of itself not unusual, it is a difficult section involving as it does new techniques as well as new concepts, and we spent more time than normal discussing the theory behind the practical considerations. As a consequence of this, the students assumed that the upcoming test would reflect this time allocation which is, in all fairness, a reasonable assumption. Something which I didn’t mention in the story was that at the beginning of the course, I gave the students a full assessment outline which detailed not only the allocation of marks but also relative weightings of each assessment item. They therefore should have known that the test was going to be primarily calculation-based, rather than practically based. But they did not make that step and were thus disappointed with the test when it came.

Another point about the testing of titrations, and indeed any practical work, is the question of how to best assess it. Clearly in the test I gave, the work was assessed on a theoretical basis, with most emphasis on the calculation side of the work. There were some questions, simple ones to be sure, on the technique of titration but the bulk of the test was about the work that follows from a successfully completed experiment. When we assess a practical section of a course such as chemistry, what are we actually assessing? If we test them with a pen-and-paper test, are we assessing the student’s practical ability or their literacy? Is it possible for a student to pass a pen-and-paper test on an experimental technique without having done the experiment? In my experience it is possible for this to happen.

There are at least two different ways of assessing practical work, both of which I have since used. One method is to use a specifically designed written test based explicitly on the actual processes of the experiment. Such a test is a useful tool for discerning if a student can remember the steps involved in carrying out a titration, and then completing the calculations associated with such a procedure. It does not however give any information as to whether the student has the skills to personally carry out the equipment manipulations necessary.

Another assessment tool that can be used is the practical test where a student is given a set of equipment, or access to a wide range of equipment, and a problem to solve. Such a test as this gives the student the opportunity to use the equipment to solve the given problem. This test will enable the teacher to watch students carry out an experiment and then check their calculations based on their results.

As is usual with a senior teaching programme, the major problem with an assessment tool like this one is the perennial one of time. It takes time to set up a test, time to set up the equipment and solutions necessary and time to carry out the test. Unlike a normal test, the time constraint issue comes up for comment. If the test is to be testing the student’s practical ability, then why must there be a limited time? In industry, whilst there are certainly rigorous time constraints, they are unlikely to be as short as a standard high school period. And similarly, would we be testing their actual ability, or just how much they can do in a short period of time?
Clearly, the assessment tool I used was inappropriate for the work we had done, but how to assess something as complex as titration is not an easy area to address. Another issue which I raise as a possibly peripheral point is that the other class who sat the same test as my class performed much better. The time my class had spent on the practical work the other class had spent solving problems, and the other class had seen a couple of demonstration titrations. As a consequence of this time spent on activity, the students in my class were disadvantaged in their final grade.

When I thought about this story, considering writing this commentary, it occurred to me to ring some chemical analysis companies. I asked the chemists working at eight such companies whether they actually used titrations in the course of their normal duties. The responses were mixed, with five companies saying that titrations were a normal, regular part of their analysis, two saying they were never used at all, and the last company said that titrations could be used on irregular occasions, if nothing else would do the job. The general impression I gained from talking to these chemists in the workplace was that the titration technique would never totally disappear, but it was gradually being replaced by new techniques. One chemist said that they use the ideas and techniques of titrations, but not with burettes and stuff, they use dosimeters. Also there was a distinct feeling that titrations belonged to 'classical chemistry', to be replaced as soon as another technique could be developed to do the same job.

However, at present, titrations are an important part of chemical analysis in the industry. This is an aspect that I have since incorporated in my own teaching of this part of the course. Now whenever I introduce this topic, I emphasise the overall importance of the technique in industry. With some of the information I gained from some of the companies I spoke to, I can describe actual analyses done in industry so as to put the experiments into a real-life context.

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Phenomenology, knowledgeability and authentic science

Wolff-Michael Roth, University of Victoria

Titrations, titrations raises many serious questions that many teachers and science educators fail to adequately address. Why do we ask students to engage in laboratory activities? What is the relationship between moving some equipment around and the canonical discursive practices students develop? What is the purpose of the activities in which students engage? and What is the relationship between these activities and the activities of scientists? and What is the relationship between the activities in which students engage in class and those they engage in during tests? In other words, to what extent do tests assess what students have learned? I begin with a reflection on the phenomenology of knowing and learning and continue to a description of authentic scientific practices.

Learning from laboratories (and demonstrations)

The most fundamental question to ask is what students are expected to learn when they engage in laboratory activities or watch demonstrations. Science education ideology and common lore holds that 'hands on' (or, more recently, 'hands-on, minds-on') helps students to learn the canonical theoretical discourses and practices of science. However, there is virtually no research that shows how and in which ways manipulating some equipment or apparatus should change someone's understanding of theoretical frameworks of science. What evidence do we have that doing a titration (even 'correctly') helps students to learn any chemistry? It has been argued that the claims about the value of traditional laboratory activities are largely unexamined and constitute a 'powerful, myth-making rhetoric' (Hodson, 1990, p. 34); school laboratory activities are largely ill conceived, confused and unproductive in that many students learn little of or about science and do not engage in doing science. To understand why this may be so, we need to take a learner's point of view on curricular activities; that is, we need to view science laboratory activities (labs or demos) from the perspective of someone who does not yet know the science these activities are intended to teach. Let us take a look at a phenomenological view on cognition.

We live in a world that we take for granted without continuously expressing how the world looks to us (Heidegger, 1977). The world is a background to our daily activities. However, when asked, we begin to focus to individuate objects and events, that is, we make some of the vaguest normalities salient and therefore 'foreground' some aspects. However, what we foreground depends on the situation and the horizon of past experiences which we bring to the situation. What we know strongly influences what and how we make salient and therefore what structural properties are that we attend to. Given the great differences between the experiences of teachers and students – or even more pronounced, between students and scientists – it is therefore not surprising that when students look at the world they structure it differently (Roth, 1995, 1996). My research showed that physics students ordered their laboratory experiences and constructed regularities in ways that were not compatible with the theory that the teacher wanted to teach (Roth et al., 1997a); and during demonstrations, students made salient aspects that were irrelevant, and even contradictory, to the laws which the teacher wanted to explain by drawing on the demonstrations as resources (Roth et al., 1997b).

These comments make it quite clear that it is therefore unreasonable to expect students to construct the same laws and theories that it took scientists
2,000 years to construct. That is, 'discovery' is largely a myth. Furthermore, students cannot just be shown some demonstration and told some structure in order for them to understand the theoretical framework of the science. The view I sketched here also provides a different frame for understanding how we might want to look at 'knowledge' and 'knowing', and therefore at teaching and learning. From a phenomenological perspective, we are always already in a world shot through with meaning. From birth on, we participate in activities which constitute the way things are for the community (Heidegger, 1977). The social and material worlds we experience are sensible because of the way we co-participate, acting in and interacting with these worlds. Such co-participation in ongoing, situated and structured activity produces knowledgeability which is 'routinely in a state of change rather than stasis, in the medium of socially, culturally and historically ongoing systems of activity, involving people who are related in multiple and heterogeneous ways' (Lave, 1993, p. 17). Lave further points out that social locations, interests, reasons and subjective possibilities of co-participants are different, and co-participants therefore engage in contingent improvisation to negotiate particular situation definitions. The production of failure is as much a part of such routine collective activity as the production of average, ordinary knowledgeability.

This is a very activity-centred view of knowing and learning. As we change our participation, we learn. But as we change our participation, the world we experience also changes. Learning is therefore constituted by changing participation in a changing world. This therefore also changes how we might look at teaching. Teaching no longer is the transfer of information but has to be conceptualised in terms of the opportunities we can set up that afford students possibilities to change their participation in a changing world (Lave, 1996). Because we participate with others, intelligibility of discourse and action are first and foremost social. Our activities, and in fact the world as we see it, make sense because we already share it within a community. That is, the consensual nature of scientists' practices arises from co-participation in accountably doing science.1

When we use this phenomenological perspective to reflect on the titration episode we begin to ask how students' activities are part of a larger whole that contextualises what they are doing. We also ask how students' changing participation in shaking the flasks and opening and closing the tap may change their participation in calculation activities. If there is little in common between participating in titration activities and doing paper-and-pencil tests, one needs to question, 'What is the value of doing titrations?' Once we decide that we want students to participate in titrating, our evaluations of their competence should be during the practice of doing titrations. Why isolate learners from the resources they have in normal activity to test them in artificial contexts and ways that give little information about competence in normal activity? Finally, and this leads us into the next section, students are asked to get the titration activities right — although they may have never co-participated in the authentic practices of titration — not to make their titrations accountable to others.

Errors and correctness in authentic science

Science educators need to ask themselves how the activities they plan for their students reflect scientific knowledge and science as practice. In my view, most science teaching today misrepresents the nature of science and interferes with rather than scaffolds students' participation in authentic practice. My own understanding of science and scientific practice comes from having worked in a research laboratory and from doing, with my graduate students, ethnographic and cognitive research on scientists' (and software engineers') everyday work. In contrast to professional science, school science activities such as the one described in Titrations, titrations have 'correct' answers held by someone, usually the teacher. Whatever students do is measured against these answers.2 On the other hand, in everyday science we most often do not know anything like a 'correct' answer. Whether some data point or a series of data points corresponds to a signal or a noise depends on the theoretical framework which researchers bring to their work and on the reproducibility of the data series (e.g. Garfinkel et al., 1981; Woolgar, 1990). Frequently, scientists engage in collective interpretation sessions during which they use processes of argumentation — at least one scientist plays the advocate for the data and another the devil's advocate — to construct some sense of whether the data correspond to a signal or noise (Amann and Knorr-Cetina, 1988). For this reason, students frequently find themselves in a quandary as to the laboratory experiments they conduct or demonstrations teachers present because, as they are to learn the theory, they do not have the tools to decide whether what they see is the signal or simply some noise not to be attended to (Roth et al., 1997a, 1997b).

Scientists, as a community, have developed a range of practices that assist in making visible signals that do not seem signals at all (Roth and McGinn, 1997). Let us take a look at an example.3 In Figure 3.1 (top), I represented an artificial but plausible curve of experimental data. Normally, these data may be taken as indicating one peak. However, if a researcher has a hunch that there are 'really' two peaks that she should expect, she might want to estimate the bandwidth of her data collection apparatus and model it mathematically. Using a mathematical process of 'unfolding', she could then recover the true peaks to look like the bottom graph in Figure 3.1.4

In a similar way, our scientist may have collected the data plotted in the top graph of Figure 3.2. Again, if she has a hunch that there really should be a phenomenon and therefore a signal instead of the virtually straight line, she may want to use a technique that is sensitive to changes. She could therefore manipulate the data she collected employing a (mathematical) derivative operator, or by using electronic means that are sensitive to changes. Such
The top graph may represent the actual data collected by a scientist. If the scientist assumes that the 'real' data are overlaid by the bandwidth of the instrument used to collect the data, they can engage in a process of 'unfolding' the data with a 'reasonable' apparatus function. Such an unfolding may then yield the 'real' function \( f(x) \) in the lower panel.

procedures, used with the data in top graph of Figure 3.2 would then give her the data as they are plotted in the bottom graph.

The point is that scientists develop in the course of their work a range of practices that allow them to bring together their expectations (theory) and the data they collect. These practices are reasonable within the community and are used to make accountable their actions. What the 'real' data are – one or two peaks in Figure 3.1 or the top or bottom graph in Figure 3.2 – depends on the theoretical baggage our scientist brought to the experiment, both the theory of nature and the theory of apparatus. Separating the signal that theory predicts from other influences is a highly situated and contingent achievement and depends on the researcher's experimental background and

Figure 3.1 The top graph may represent the actual data collected by a scientist. If the scientist assumes that the 'real' data are overlaid by the bandwidth of the instrument used to collect the data, they can engage in a process of 'unfolding' the data with a 'reasonable' apparatus function. Such an unfolding may then yield the 'real' function \( f(x) \) in the lower panel.

Theoretical understandings of the domain and possibly hunches about what the phenomena could reasonably – that is, defensibly and accountably – look like. Whether the data are 'real' and correspond to a phenomenon depends on the researcher's competence in making the experiment and her analysis accountable within her own research community. Whether the wiggles on the original graph in Figure 3.2 (top) are due to experimental error or whether they in fact can be used to disclose some phenomenon cannot be established beforehand, but has to be embedded within a range of practices that allow scientists to make their accounts credible. In this process, even questions such as whether a second run can be considered the same (and therefore a candidate for assessing confirmation or disconfirmation of the first) or whether it was in some aspect different are embedded within the contingencies of scientists' laboratory work.
In contrast, the kind of laboratory work that students did in the titration story is predictable from the very beginning. Here, we do not deal with ‘discovery’ work but with the nitty-gritty of technicians’ work, which, though exciting, reveals little of the exhilarating experience of the discovery sciences and the ways and means by which scientists construct the knowledge that we later come to accept as ‘truths’. Students learn little about scientists’ purposes for using precision in titration, about making their actions accountable to research co-participants and to the research community at large. Given these stories about ‘real’ science, how can anyone expect students to get it right on the first time? How could they be able to separate signal from noise? How should they know which is the signal that is relevant to the phenomenon at hand?

As a community, science educators and science teachers need to change our thinking about teaching and learning. At the moment, students and teachers focus on grades. What we need to do is change teaching practices to make them compatible with the learning perspective espoused in these reflections. As a community, we need to bring about co-participation in sensible and plausible activity and the production of ordinary knowledgeable in chemistry (and other sciences); we need to bring about contexts with a primary purpose of learning rather than grading; and we need to bring about contexts in which producing reasonable accounts guides students’ laboratory activity rather than getting some purported ‘right’ answer.

Assessment and students’ interest: connecting to learning

Penny J. Gilmer, Florida State University

Considering forms of assessment

Bevan McGuiness listened to his student respond to his question about why the students did so poorly on the unit examination on titrations, ‘Oh yeah, you did [emphasise the calculations at the end]. But we spent all that time on the prac. So we thought that was the big thing.’

As teachers we must remember that both the method we choose to assess our students’ learning and what we emphasise during class time drive the students’ learning. Bevan chose to assess his students’ learning by an end-of-the-unit examination on titrations that emphasised the ends (i.e. the final calculations and error analysis) but not the means to the learning (the practicalities of preparing a standard buffer, titrating the base, and using that standardised base to determine the concentrations of unknown commercial acids). Bevan’s students spent many class periods learning the process skills of conducting titrations but only the final day of the unit calculating the concentrations of some commercial acids and doing the error analysis.

Capturing our students’ interest

A teacher needs to capture the students’ interest for the student to learn the complexities of titrations including, as Bevan wants, the ‘joys of titres, aliquots and equivalence-points’ and of the error analysis. For instance, Bevan’s students might be interested to know that there are natural indicators in certain plants called anthocyanin dyes that give geraniums, raspberries, strawberies and blackberries their red colour. Poppies get their red colour from a cyanidin dye that is red when in acidic conditions but blue with basic conditions. It is actually the sap of the plant that controls the pH of the flower, so poppies’ sap is acidic leading to red flowers and cornflowers’ sap is basic, giving blue flowers. These natural dyes are used sometimes in foods, as people discovered that some of the artificial red dyes caused cancer in laboratory animals (Oxtoby et al., 1994). Ideas like this might get Bevan’s students to see the relevance of chemistry and why it interests people. The power of chemistry is that it can explain so much of the world.

Sharing personal experiences in chemistry

I always try to give some practical experience from my life as a chemist on how the topic under study has been important in my career. For instance, with titrations, when working on my doctorate in biochemistry at the University of California, Berkeley, my research contributed towards an understanding of the mechanism of action of a particular transaminase enzyme as it formed a covalent bond with one of two substrates. The person who had studied this enzyme previously had reported that there were two active sites per tetrameric protein (i.e. two binding sites for the substrate to this enzyme with four identical protein chains per intact unit). Not intending to observe anything different than what was reported previously, I titrated the enzyme with the substrate, quantitating it by using a visible colour change that occurred on binding. From my very first experiment I found that my data indicated that there were four binding sites per tetramer (Gilmer et al., 1977), and it took me a year’s worth of experiments to convince my directing professor that the literature was wrong. This story always impresses students that science is an incremental process of understanding and that it is rigorous. However, I also share with my students how good I felt when my major professor did a titration himself of the same enzyme but with another substrate that he was studying, and he confirmed my report of four binding sites per tetramer.

Using the Internet

Another thing that might have helped Bevan’s students see the importance and practicality of determining the concentrations of the commercial acid products would have been to encourage his students to look on the Internet
for practical applications of doing titrations. His students might have even selected a commercial product that they wanted to titrate.

Alternately, Bevan’s students might have become interested to determine the amount of acid in acidic rainfall isolated from different locales within their country. The students would become motivated to do a standard titration first to develop their methods, so that they could test unknowns that could be more meaningful to them. When testing the samples of acid rain, instead of having a fully outlined procedure, students would have to think about how to conduct the experiment so the results would be meaningful and reproducible. Bevan’s students would come to know science as it is done, with its frustrations and rewards. They could take ownership of their own data. They could also interact with students around the world who are conducting similar studies through Project GLOBE on the Internet at <http://www.globe.gov>.

For a chapter on acids and bases in a biochemistry course that I recently taught at university level, students became interested in the practical applications of buffers through searches on the Internet. My students found that buffers are used in electrophoresis of DNA to determine gene sequences and in feed for cattle, to increase the mass of beef.

**Using portfolios in assessing students’ learning**

Bevan might have included within his assessment, not only his traditional end-of-the-unit written test, but also alternative assessment such as his students’ learning of their Internet project. Since many students do not know how to use search engines on the Internet, Bevan would have had to teach them how to do that. When students are given freedom to explore, they will innovate and find all sorts of things that the teacher did not realise beforehand. This means that the teacher must be a learner too, be open to learning from his/her own students, but at the same time also be critical and questioning of what the students proclaim.

I find in my own class activities that if I have the students work in collaborative groups, it helps the students learn, as they must use the language of the discipline, as they try to explain to each other what it is that they know as they teach each other. Students all come to the classroom with their own prior knowledge and experiences (Glasersfeld, 1989). Each student can share understandings with peers in the classroom. Students can learn from each other as well as from the teacher.

For Bevan’s assessment of what his students contributed and learned, each student could write an entry into a portfolio which contains evidence of the student’s learning (Collins, 1992). I have found it helpful to guide the students in their writing by having them follow a written rubric of what the students should include. For instance, my most recent five-point rubric (which is always evolving) for individual students’ electronic portfolios included:

- Sharing accurate understanding of the science content (helping both the student to utilise the discourse of science and the teacher to realise students’ misconceptions)
- Using good grammar and spelling to communicate learning (helping the student to communicate more clearly)
- Reflecting on prior learning and current learning (helping the student link what he/she already had learned to new learning; students also realise through reflection what helps and inhibits their learning)
- Referring where the student learned additional material (from a website, book or newspaper article that the student has found that facilitated learning)
- Asking a good question that the student still has in his/her mind at the end of the student’s research (giving the teacher a window into the student’s mind to see how far each student is in his/her learning)

It takes time for the teacher to read what the students have written and to respond individually. However, doing this allows the teacher to start to connect to his/her students’ learning, to find out what the students know and don’t know while still teaching the unit. As the teacher does this and reflects on his/her teaching, the feedback the teacher receives influences the teaching later in the week. Instead of finding out at the end of the unit what the students do not know, the teacher finds out while there still is an opportunity to change emphases, clear up misconceptions and enhance learning in the classroom. This is the first step towards conducting action research in your own classroom. Action research in elementary (Spiegel *et al.*, 1995), middle (McDonald and Gilmer, 1997) and high school (Yerrick, 1998) settings can provide teachers at all levels with visions of how to improve science teaching and learning in their own classrooms.

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**Editors’ synthesis**

Perhaps more than most laboratory activity, titration technique in school chemistry has been raised to the status of high art (or science). In some parts of the world, serious state and national competitions are held for school students to demonstrate their titrations skill. This emphasis on perfecting the technique appears as the overriding focus of the lesson described in *Titations, titrations* (the word ‘technique’ appears eighteen times in McGuiness’ story and commentary). The zeal with which this teacher pursues titration technique will, no doubt, be familiar to those who have taught senior chemistry. However, given the critiques of laboratory work offered at the beginning of the chapter, we are left to wonder how this kind of activity might rate as ‘authentic’ science. Several angles on this issue are provided by the commentators.
The first angle is that the science laboratory needs to proceed in an atmosphere of accountability rather than rightness. As Roth suggests, ‘we need to bring about contexts in which producing reasonable accounts guides students’ laboratory activity rather than getting some purported “right” answer’. This is a complex business, as Roth points out, as knowledgeability develops from a culture of co-participation in ‘ongoing, situated and structured activity’. Roth draws parallels with images of scientists at work. His observations of the complex social milieu of conducting science is confirmed by Gilmer’s account of her doctoral research in biochemistry. Apart from doing endless titrations, one of Gilmer’s major tasks was to convince her direct professor that the literature was wrong. Authentic school science, according to these commentators, develops within a context of persuasion, negotiation and argumentation.

Secondly, the titration activity needs to be considered in relation to its scientific, problem-solving context. The importance of capturing student interest is raised by Gilmer in her discussion of the value of studying plant dyes, commercial acid products and acid rain. However, capturing interest is a tricky business as Gilmer’s own experience can testify. Her own research on the properties of a particular transaminase enzyme clearly captured her interest at the time, but would likely have been of little interest to more than a few others. Clearly, though, authenticity contains important elements of relevance and interest to the individuals concerned.

A third angle considered by our commentators is that the activity needs to tap into ‘real world’ resources and techniques. As McGuiness observes, while burettes may still be used in some chemistry laboratories, they are rapidly being replaced by more modern tools. Gilmer canvasses some of the possibilities of using the web to explore some of the practical applications of titration chemistry. Other possibilities include the use of computer simulations. As the respondents to McGuiness’ straw poll indicated, it is not the ideas behind titrations that are being superseded but the equipment and the particular skills for using that equipment. Authenticity, it would appear, involves approaching scientific problems using a range of resources and techniques.

The final angle concerns the relationship of the activity to the assessment practices. All three commentators draw attention to mismatch between the activity in the story (with its emphasis on process) and the assessment (with its emphasis on calculations). While McGuiness offers several possibilities for rectifying this situation including a practical test where students are given ‘access to a wide range of equipment, and a problem to solve’, he still hints at the need to check the students’ answers. Roth proposes that assessment should be conducted in normal rather than artificial contexts, based on the notion of explaining to others rather than getting right answers. In Gilmer’s commentary, she suggests that assessment be based around the means to learning (such as the practicalities of preparing a standard buffer) rather than the ends (the final calculations). She also explores some of the possibilities for using portfolios (including electronic portfolios) to tap into students’ understandings. Authentic laboratory work, it would seem, needs to be matched by authentic assessments.

These four angles on authenticity – about social context, relevance, resources and assessment – provide some ways of interpreting the events in the story, Titration, titrations, and some ideas about how to move forward. It would appear that it is not necessarily titrations (or even technique) which is the issue in this story but the social, intellectual and cognitive milieu within which this laboratory activity is located. It is entirely possible that titrations (and technique) can be part of authentic scientific practice, as Gilmer’s own research experience can attest. However, Gilmer’s experience was part of a scientific, rather than a school science, endeavour, with different norms of conduct. The challenge for McGuiness and his fellow science teachers is to find ways of assisting students to develop parallel norms of behaviour, to marshal the social and cognitive resources to conduct authentic laboratory work.

Notes

1 Etymologically, words such as communicate, community, consensus and collaborate derive their first syllable from the Latin cum, meaning ‘with’. Communication and community therefore always and already presume our being with others, allowing us to share, have something in common, consent and collaborate.

2 There is research that shows that even the best-trained teachers sometimes assume they have the right answer which leads to the interesting situation that students’ tests are compared to standards that are not in agreement with the scientific canon (e.g. Roth et al., 1997b; Roth et al., 1996).

3 During my M.Sc. research, I (Roth) saw many such graphs being collected from experiments in which electrons were made to interact with gaseous matter. The data collected by the astronomers in Garfinkel et al. (1981) could be of this nature.

4 To produce these data, I (Roth) took the reverse direction. Beginning with the ‘real’ function, I folded it (‘covered it up’) with an apparatus function. Interested readers may obtain the actual calculation by writing to me.

References


