

Experiences with LabTrove, a researcher-centric ELN: undergraduate possibilities and Twitter

Mellor Lecture of the UNSW Chemical Society Delivered on 9 May 2014

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Abstract

Electronic Laboratory Notebooks (ELNs) are progressively replacing the traditional paper books for recording of data and scientific reasoning in commercial research establishments and academic institutions, albeit not at UNSW Australia. The LabTrove ELN was designed and developed at Southampton University as an open source, web-based, recording system that is researcher-centric and can be tailored to meet the needs of individuals as well as entire research groups. The LabTrove system also ensures appropriate levels of security, and captures the meta-information necessary to establish reliable provenance. It is designed to promote cross-institutional collaborative working, to enable the sharing of procedures and results, and to facilitate publication.

LabTrove is being used in a heterogeneous set of academic laboratories around the world. At UNSW Brynn Hibbert's group has used, in part or in whole, this ELN. An Australian Learning and Teaching Council (ALTC, now OLT) grant allowed the development of a collaborative ELN for undergraduate analytical experiments. With the Universities of Sydney, Curtin, Chiang Mai (Thailand) and Southampton (UK) experiments were developed and tested that involved students from pairs of institutions, sharing data and interpretations but being assessed in their own departments.

As an example of the use of social media in chemical education, Twitter has been used as a channel of communication between lecturer and audience of 500 + first year undergraduate students. During the Mellor lecture feedback from the audience was solicited by a running monitor of a Twitter hashtag (#mellor2014) projected on a screen. Tweets from Sweden and other locations were accepted during the lecture.

1. Introduction

Professor David P. Mellor (1903-1980) was Head of the School of Chemistry at UNSW from 1956 to 1968, having spent 26 years at the University of Sydney, followed by 14 years as Professor of Inorganic Chemistry at UNSW. His research interests were mainly concerned with the properties and structures

of metal complex compounds. He also made considerable contributions to chemical education at the secondary and tertiary levels. David Mellor was President of the Royal Society of New South Wales in 1941.

Since 1960 UNSW has been active in developing new approaches to the teaching of chemistry within secondary schools through

its summer schools, the proceedings of which were published in the *Approach to Chemistry* series, including the commercially published *Chemical Data Book* (Blackman and Gahan, 2013). Using the royalties from these publications, the David Mellor Chemical Education Fund was established in recognition of the contributions made by Professor Mellor in the field of chemical education. The Fund is used to endow the Mellor Lecture and Medal. This Fund is administered by the University, with the involvement of the UNSW Chemical Society in the organization of the visiting lecturers.



Fig.1: David Paver Mellor (1903 – 1980).

Professor Hibbert was the first Mellor medallist from UNSW. A list of Mellor lecturers and medallists is given in Table 1.

2. Recording of Science

It may no longer be fashionable to discuss the Scientific Method, or even to explain it to our students, but it must form the basis of any approach to recording and disseminating

what we scientists do. The on-line Oxford Dictionary (Oxford English Dictionary, 2014) defines scientific method as:

“A method of procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses.”

Table 1: Mellor lecturers and medallists of the UNSW Chemical Society

Date	Lecturer	Institution
1972	L.E. Strong	Earlham College
1974	J.H. Wotiz	Southern Illinois University
1975	D.M. Adams	University of Leicester
1979	D.R. Stranks	University of Adelaide
1980	R.J. Gillespie	McMaster University
1981	A. Kornhauser	University of Ljubljana
1983	P.J. Fensham	Monash University
1984	P. Sykes	Cambridge University
1987	A.H. Johnstone	University of Glasgow
1995	C.A. Russell	The Open University
1998	T.E. Goodwin	Hendrix College
1999	B. Selinger	Australian National University
2003	S. Warren	University of Cambridge
2008	L. Sydnes	University of Bergen
2014	D. B. Hibbert	UNSW Australia

The results of the application of the scientific method are communicated to the world, and this is how we scientists are known. However from the start of the ‘formulation of

hypotheses' we need to document what we do. Not only to provide a historical record, perhaps one day for the Nobel Prize committee, or to establish our patent rights, or to ward off later investigations into scientific fraud, but to get our own thoughts in order and provide a narrative for our research.

The paragons of recording their science, according to Bird, Willoughby and Frey (Bird et al., 2013) and starting with Leonardo da Vinci, through Michael Faraday, Charles Darwin and Albert Einstein (and others) kept diary style notebooks. Paper was the only medium available, and paper was also the means for communicating with fellow scientists, either by personal letter or by publication in a learned journal. Data, obtained by observation and experiment, was also directly recorded in the notebook, as was information derived by analysis of that data. So Faraday had his notebooks, and indeed I had mine. I managed my three-year PhD with just two, and a third for theory.

Last year (2013) the School of Chemistry stores at UNSW issued 400 laboratory notebooks at a cost of A\$5600 which gives two to three books for each researcher per year. (About 130 PhD and honours were in the School in 2013).

Modern instrumental science, and this is certainly true of analytical chemistry, generates results at a great pace. Because of this, I believe it is evident that the trusty lab notebook has run out of pages to record all the data, and unfortunately we seem to have finished up with the worst of all worlds – we no longer can fit the reams of printed out spectra, graphs and so on between the blue covers, and of course cannot use them to store the 'raw data', but neither are we writing there the hypotheses, observations and

inferences that are the core of the scientific method.

To go from an experiment to what is revealed to a supervisor in a research group meeting is these days a long and drawn out process:

Instrument → raw data on instrument's computer → transformed data (proprietary software, spreadsheet) on student's computer → printed out graphs or transcribed numbers in student's notebook → and presented in PowerPoint.

What is finally shown by the student to her peers is highly selected (by the student) and not (easily) traceable to original results. Files on the student's computer are often not adequately backed up, or even decently indexed, and a consultation with the student can be a frustrating wait while folder after folder on their hard disk is searched through. A polite enquiry after, for example, a control experiment, can result in a panic trawl through files, or bland assurances that this has been done somewhere, and they will find it for you later.

Since the US Supreme Court passed rules accepting electronic records as equivalent to paper records in 2006, the headlong charge to the use of ELNs has been led by the patent juggernaut, which of course features many big chemical companies. In a review of ELN use, Phillips is quoted by Bird (Bird et al., 2013) as suggesting that the distinction between companies and academia is that large companies typically use ELNs to standardize quality control or establish a legal data trail; while academic labs use them to gain searchable access to, and then share, data. She identifies one of the greatest problems faced by an academic group is the turnover of personnel, resulting in an almost impossible task of retrieving data from only a few years

back. The ability to share data also has implications outside a group/ laboratory/ department/ university, more of which later.

2.1 Practicalities

In 2014 we are spoiled for choice. There are app ELNs, cloud ELNs, ones aimed at companies, ones aimed at data intensive research groups, and so on. In 2009 the analytical chemistry group of the School of Chemistry at UNSW started using the LabTrove ELN² because it was developed by a colleague and collaborator from Southampton University, Jeremy Frey, and he gave it to them for free. Luckily the company they spun out has thrived, and the product is still supported by academics.

But in 2009 not all the attendant and required technology was in place. When the School of Chemistry started using the ELN there were no real smart phones as such (the 2G Blackberry was all the rage) and certainly no tablet computers. Voice or even handwriting recognition software was hardly viable. The final killer, at the time, was the lack of a ubiquitous wireless network. So students tended to use the ELN off line, and while the physical cutting and pasting of instrumental output also must be done back in the office, there was never a wide uptake of the ELN.

Many of these issues are much improved, but the bottom line always appears to be the social and local political aspects, with resistance to change coming from all levels of a laboratory, from the students upwards.

Perhaps Bird and Frey got it right when they wrote last year: “*Unfortunately the evangelists are frequently not the same individuals that will be creating the data and recording their work in the*

electronic laboratory notebooks” (Bird and Frey, 2013).

(In the lecture delivered on 9 May 2014, a comment followed on proposals from the Australian Federal Government on the funding of higher education and the suggestion that the tertiary sector be deregulated. It is not reproduced here.)

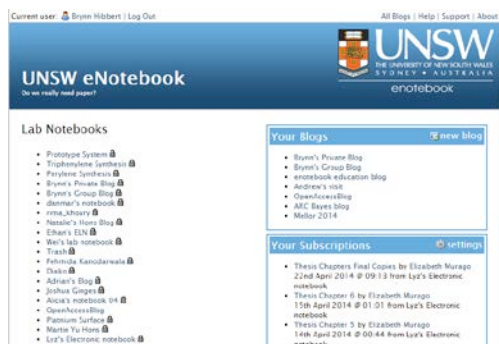


Fig. 2: The front page of the ELN used by the author's group. (Image taken 5 May 2014)

We left the direct scientific descendent of Michael Faraday, Brynn Hibbert, doing his PhD in London's King's College in 1973, writing in his lab note book without so much as a spreadsheet or printout. He visited the Royal Institution as Daniell (first professor of chemistry at King's College, and one of the founders of the delightfully named “Society for the Dissemination of Useful Knowledge”) would have visited Michael Faraday there. Not much had changed from a hundred or so years before, with data being largely recorded by hand. Sure he had spectra, assuming the ink in the pen of the chart recorder drawing out the trace had not congealed, but most data were measurements made point by point. The other aspect of science that had not changed was that communication was by physical letter, and publication by book and paper written for a journal.

² See <http://www.labtrove.org/> (Accessed 13 May 2014)

Now, in 2014, for scientists, publication in a journal (paper or on line) is still the preferred mechanism for enabling wider access to their material and providing the appropriate recognition for their work, although such publication does not constitute a full archival record, and many authors have pointed out the shortcomings of a paper-based mode of making scientific results available (Bartling and Friesike, 2014). Communication in general, though, is wider and faster, invariably electronic and often broadcast. With these possibilities for instant peer-to-peer interaction we have the decision to make about how open we will be with our ideas and knowledge. Indeed in a discussion (Gezelter, 2011) of the definition of ‘open science’ “... *the idea that scientific knowledge of all kinds should be openly shared as early as is practical in the discovery process*”, the point is made that journals are 17th /18th century technology for sharing scientific discoveries and today, we should be able to do better.

Much discussed in the literature is the ‘collaboratory’, defined in 1993 by Wulf as a: “... *centre without walls, in which the nation’s researchers can perform their research without regard to geographical location interacting with colleagues, accessing instrumentation, sharing data and computational resource, and accessing information in digital libraries.*” (National Research Council, 1993). To what extent this is achievable or desirable, may be debated, but it does now open up the discussion of the real role of the ELN, that of communication.

So I have finally arrived at my point. An electronic laboratory notebook has the capacity for immediate open access and sharing. There are many other benefits of security, metadata and audit trails, but in my view the possibility of throwing open the lab doors and allowing the world to help, is the most revolutionary aspect of the ELN, and

why no one feels they can go there yet, or at all. The School of Chemistry ELN can be set to allow access by everyone, no one or anyone. If we look at an ELN post, it allows comments to be added – very useful for the supervisor to comment on the fly, but this has much wider possibilities. Access is usually restricted to the immediate research group. When we set it up I (as group leader) hoped there would also be student-to-student interaction, and while there are some examples student-to-student posting has not become widely used. But wouldn’t it be nice if on posting the results of today’s experiments a comment appeared tomorrow from another group around the world with a new idea, or simply some encouraging words?

I cannot help but remember the Djerassi and Hoffmann play “Oxygen” (which I saw at an IUPAC General Assembly 2001) that explored the question “who discovered oxygen”? Every English scientist is brought up to know Priestley as the discoverer because of his work “Experiments and Observations on Different Kinds of Air”. But he visited Lavoisier (who named the new gas oxygen and worked out why it was not de-phlogisticated air) in 1774, only to receive a letter from Carl Wilhelm Scheele also describing experiments on the production of oxygen, but from the previous year. It appears communication between people came first (letters and visits) with publication somewhat later. The question of discovery may have been asked at the time (of course Lavoisier was soon busy having his head chopped off), but it seems now a modern fascination of who got there first, rather than why ‘there’ is important. The time it took to evolve Darwin’s “On the origin of species”, or in my field the posthumous publication of Bayes’ paper on “An Essay towards solving a Problem in the Doctrine of Chance”, suggested our forebears had understood the

importance of real communication, not just having another paper in the publication list.

And if you see where this is leading, the position of the formally-submitted and reviewed and published paper is perhaps under threat, as now being an obstacle to scientific progress. At one end the monograph or lengthy review article will always be needed, and at the other the Nature letter fantastic discovery is more and more electronic first anyway, but what of the interminable number of papers churned out after careful, or not so careful, peer review, simply to document the filling in of gaps in an evolving field? Is there a better way of compiling this knowledge, giving due credit to its originators, than in papers whose main text hardly has sufficient details to allow reproduction of the experiments, but more and more voluminous supplementary material is filling in some of the gaps. Do we have to have the formulaic introduction that is cut and pasted from paper to paper in a series, or the reference to a method that, if you can find it, turns out not be able to be followed?

I argue that we now have the means to put in place these new, instant, modes of communication of science, and here I am just echoing people like Cameron Neylon and our own Matt Todd from Sydney.

I shall conclude this tirade with a quote:

“[the Review would urge]... all scientists to learn to communicate their work in ways that the public can access and understand; and to be open in providing the information that will enable the debate, wherever it occurs, to be conducted objectively.” (Russell, 2010)

Why this comment is significant is because it is from the Independent Climate Change E-mail Review, occasioned by some unfortunate language about scientific results in internal emails between climate scientists. That is, we

must always “show the working” (Hulme and Ravetz, 2009). I learned yesterday (8 May 2014) from Matt Todd, that they have lodged a copy of the relevant posts of an ELN as supporting information for a research paper that is being submitted for publication to a journal. The snapshot (once unzipped) can be browsed, and contains all the relevant experimental data from the original “live” electronic laboratory notebook (Badiola and Todd, 2014).

Finally, UNSW is not without its research scandals (thankfully not so many) and I cannot help but think experiments properly captured in an ELN might have saved, certainly the Faculty of Medicine, some pain.

3. Extensions and Additions

The LabTrove ELN used at UNSW (Fig. 2) is a web-based highly-linked blog, with layers of metadata. There is not much else to the basic blog page. Files can be attached, and now, through the ANDS-funded ACData project (Fig. 3) it is possible to blog results directly from instruments in the Analytical Centre and some electrochemical instruments in our labs.



Fig. 3: A page from the UNSW repository of instrumental data, ACData. (Accessed 13 May 2014)

The original driver for this was to satisfy government archiving rules, but it also helps (forces) experimenters to organise their work (Project/ Experiment/ Batch/ Run), and naturally fits with the ELN concept. Those

who submitted ARC Discovery proposals this year might have wondered what the formula text was for the section “Management of Data”, which reads “UNSW has implemented a data storage solution for every stage in the life cycle of a research project”. Well, ACData is a big part of this for chemistry, and using an ELN makes it easier.

Hopefully ACData fulfils the observation of Huynh-Ba and Aubry “*On a practical level, a full electronic notebook, however desirable it may be, is not practical until all the instruments in a laboratory are computerized and networked.*” (Huynh-Ba and Aubry, 2000).

[Suggested Linked Data \[show/hide\]](#)
 Note : These links are not saved as part of your blog. Links are created when you edit your ELN entry. You can also fine-tune the suggested links.

<p>Chemspider Info</p> <p>methylamphetamine Confidence : 0.98 Hide ChemSpider data</p> <p>Data collected on : 2014/05/05</p> <p>ChemSpider url: http://www.chemspider.com/RecordView.aspx?id=1169 id: 1169</p> <p>image: http://www.chemspider.com/ImagesHandler.ashx?id=1169 molecular weight: 149.2328 molecular formula: C₁₀H₁₅N smiles: N(C)CC(C)CC(C)C inchi: InChI=1/C10H15N/c1-9(11-2)8-10-6-4-3-5-7-10/h3-7,9,11H,8H2,1-2H3 inchikey: MYWUZJCMWCOHBA-UHFFFAOYAT average mass: 149.2328 monoisotopic mass: 149.120453 nominal mass: 149.0 common name: Methamphetamine</p>	<p>References from Pubmed Show pubmed references</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> methylamphetamine <input checked="" type="checkbox"/> isopropanol <input checked="" type="checkbox"/> water <input type="checkbox"/> methyamine hydrochloride <input type="checkbox"/> hydrochloride <input type="checkbox"/> chloride <input type="checkbox"/> p2p <p style="text-align: right;"><input type="button" value="submit"/></p> <p>Query: methylamphetamine AND isopropanol AND water.</p> <p>Title: Capillary zone electrophoresis (CZE) coupled to time-of-flight mass spectrometry (TOF-MS) applied to the analysis of illicit and controlled drugs in blood. Authors: Gattardo Rossella R Department of Medicine and Public Health, Unit of Forensic Medicine, University of Verona, Verona, Italy. Polettni Aldo A Sorio Daniela D Pascali Jennifer Paola JP Bortolotti Federica F Liotta Eloisa E Tagliaro Franco F (click to see/hide the abstract)</p>
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Fig. 4: ChemSpider and Pubmed information obtained automatically from an ELN entry containing the chemical ‘methylamphetamine’. (Accessed 19 May 2014).

The ELN is evolving with new features such as time-line view, and the identification of chemical substances in each post. The latter was the outcome of a very nice project between Chemistry, the UNSW library and CSIRO. An ELN post turned out to be the ideal test bed for their developed software that falls in the class “semantic text miner and tagger”. A script is run once a day on the ELN to search for chemical key words in the text of any blog. When a substance is

identified the ChemSpider record is looked up and main data is displayed with link to the full record.

4. Undergraduate use of the ELN

In 2010 a consortium of ELN aware colleagues, from UNSW, University of Sydney, Curtin University, Southampton University and Chiang Mai University in Thailand, with UNSW as lead institution, put together a project proposal “Extending the science curriculum: teaching instrumental science at a distance in a global laboratory using a collaborative electronic notebook”. The goal of this project was to develop a framework for the incorporation of laboratory-based teaching into a global web-based undergraduate tertiary curriculum. The framework provides science educators with the tools necessary to implement an undergraduate course in the analytical sciences across two or more institutions, located within the same country or across international borders.

Unlike many web-based projects that focus on doing experiments at a distance we did not concern ourselves with how to control an NMR from the Moon, but on the peer-to-peer collaboration between students (and incidentally staff) in the context of an undergraduate lab. It was originally envisaged to be a series of five-way experiments, with one site actually performing the measurements and all sites receiving the data (via the ELN) and discussing, before individually writing up to satisfy their own assessment requirements. The vagaries of university terms (not so much time zones) meant this was never achieved, but quickly it was realised that this approach was most likely to be pursued in a one-university-to-university mode.

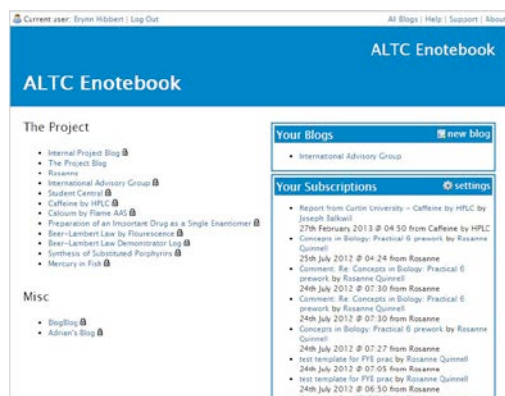


Fig. 5: ALTC electronic laboratory notebook. <http://altc.ourexperiment.org/> (Accessed 5 May 2014)

An unexpected bonus of the experiments developed for this project was the realisation that more traditional synthetic experiments may also be delivered via a collaborative web-based laboratory course. This can be carried out either by having local and remote students prepare analogues of the same basic compound, and then provide a collaborative interpretation of the data obtained. Alternatively the various cohorts can develop different approaches to a specific synthesis which is then collaboratively assessed to develop the “best” guidelines for synthesis. Matt Todd from the University of Sydney led this approach, and if you have not seen it, I would commend his open project to resolve the enantiomers of praziquantel, an effective drug against schistosomiasis (a water borne disease affecting some 200 million people) (Woelfle et al., 2011). The web site for the undergraduate ELN project can be found at <http://altc.ourexperiment.org/>.

Experiments on the analysis of caffeine in drinks and mercury in fish are based on traditional laboratory experiments used at UNSW in a third year analytical chemistry course and provide examples of experiments that can be done at one location with the results loaded to the ELN and then used by

all. If several institutions that can measure mercury levels are involved in the course then obtaining data for mercury levels in different parts of the world becomes possible, with comparisons of results and resulting cross-cultural discussions.

This mechanism has the potential for helping developing countries at marginal extra cost to the host institution. Say a university like UNSW is doing an experiment requiring LC-MS-MS, an instrument not owned by Chiang Mai. In a collaborative experiment, students at UNSW perform the experiment as they would normally do, but the results, raw data especially, are posted on the ELN for the group in Thailand. With the possibilities of high levels of interaction between the students, it is hoped that peer-to-peer mentoring happens without any fuss and the students in Thailand receive as authentic experience as possible without actually having the instrument in their lab.

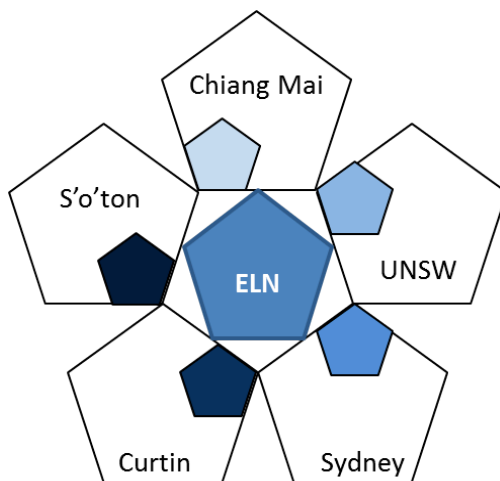


Fig. 6: Schematic of the electronic laboratory notebook (ELN) interacting with the five participating institutions.

Jeremy Frey from Southampton University offered an experiment to measure the extinction coefficient of an organic dye that

could actually be done over the internet, with a permanently running laser set up that could be turned on and fired over the web.

Although the development came at the end of the project we recognised that ACData could provide a long term and secure archive that can inform future courses. In quality assurance in laboratories, we use data collected over time to measure and monitor repeatability and reproducibility of results. In contrast in an afternoon of experimenting, when the students find themselves taking a standard deviation of three or four results, access to long run data allows a more authentic experience.

5. Social media in large lectures

Wikipedia lists 204 social networking sites headed by Facebook, Twitter, & LinkedIn, but then followed by Chinese and Russian sites the author has never heard of. As an aside, if the academic reader is concerned about the accuracy of Wikipedia, the author has just published a paper on the analysis of new synthetic cannabinoids (Lum et al., 2013) in which a table listing these compounds from Wikipedia is reproduced; this listing being far in advance of any official compilation. There are increasing opportunities for use of social media in research and education. Even the most staid journals these days invite you to 'like' them and their articles on Facebook. A new project on the social presence of IUPAC has just been approved. Headed by a Young Observer from last year's General Assembly in Istanbul, it has taken nearly a year to gain approval, perhaps because of a perception that such modes of communication are not necessarily for the peak International body in Chemistry. Yes they are.

The idea of using Twitter in chemistry at UNSW appears to have arisen simultaneously

between Marcus Cole and myself (Cole et al., 2013). The concept was to open a channel of communication to a group that was too large to interact with individually in the largest lecture theatre on campus (Clancy theatre with a capacity of over 1000).

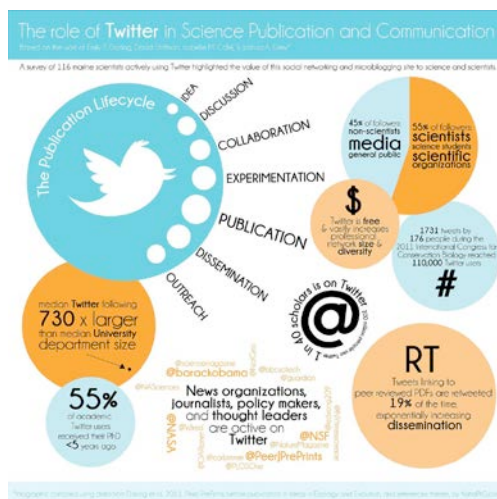


Fig. 7: Info graphic showing Twitter use in science communication. Reproduced from <http://visual.ly/twitter-and-science>, designed by 'KatiePhD' (Dr C.A. Pratt) <http://www.katiephd.com/>.

No student is going to put her hand up half way back in the Clancy to ask a perceptive question. With the hash tag #chem1011 and a Tweetdeck feed projected during the lecture, on the first day for some time absolutely nothing happened. I then asked anyone to tweet anything, to receive a question on how I first grew my beard. Once we had got that out of the way I asked them what was the last element that had been named by IUPAC? Quickly "Copernicus" came back, which I was reasonably happy with. We had just named Copernicium, element 112, so that was pretty good. When I explained the naming rules, a follow up tweet suggested that was what he had written but that the "spell checker changed it".

A year or so later we ran some surveys, using my own social network of psychologist Professor Jim Kehoe, and wrote up the paper that appeared in *J Chemical Education* in April 2013 (Cole et al., 2013). The usage was steady (about 10 tweets per lecture) without being overwhelming. About two thirds of tweets were about the lecture material or at least relevant to the course. The remaining third was an interesting mix of jokes, birthday greetings and general social glue. After the lecture, tweets followed up on questions. An interesting statistic was that only 23% of the class had a twitter account at the start of the project. (Present surveys in the US suggest it is over 80%). The bottom line showed 72% respondents in the survey thought Twitter helped learning, but there was some feeling that in the lectures it had the tendency to distract and intrude. Of course the Twitter feed can also be suspended or simply switched off, and used between lectures. Twitter, and other social media, is increasingly used by scientists to communicate and interact, among their professional communities and to quickly get their message out to the world. Fig. 7 is an infographic from 'KatiePhD' called "How Twitter can benefit scientists in terms of effects on publications, communication and outreach".

6. Conclusions

This paper has not been a hard sell for a particular electronic laboratory notebook. In writing this, the author has realised that whether UNSW Australia wakes up to the new technologies sooner or later is no longer the point. The world has advanced. What we do need to think about (as part of the discussion that is not happening either), are the kind of education and activities that should take place in a 21st century institution called a university, and how we expect our students to communicate the products of their scholarship and learning. I argue this

should not be just in their theses, or even papers for which their supervisors take equal credit, but in a continuous peer-to-peer exchange of ideas, data and knowledge, conducted, in part, through web-based tools.

So if I have in anyway stimulated or interested you, do not forget to like me on Facebook!

Thank you!

7. Discussion

The full discussion after the lecture is not presented here. The question that created the most debate came from Dr Jon Beeves (UNSW): "*Why would I give away all my unpublished results and allow others to publish it first to doom my career?*" There is genuine concern about groups, often in nations that are rapidly developing their scientific research, that 'borrow' ideas, and even data, from established sources in order to re-publish without acknowledgment. Dr Beeves argued that this would increase in an open science regime. The reply was twofold. First, plagiarism is as old as the proverbial hills, and increases with the amount of material that can be plagiarised. This is not the fault of open science. Second, making data and hypotheses available in an open source *is* publishing. Each post in an ELN is date and time stamped, and the source can be readily verified. This is more protected than a careless remark in a lecture at a conference, for example. So we are left with the concern that someone might 'stand on the shoulders of giants', by taking your results and then extracting the great idea of the age before you have had the same thought. Perhaps they might. A possible example of this scenario might have been the discovery of the double helix by Crick and Watson. We learn in "The Double Helix" (Watson, 1968) that Linus Pauling had theorised a triple helix, a structure that was instantly ruled out by the X-ray

patterns obtained by Franklin and Wilkins, and known only to Crick and Watson. Had these patterns been available to the world as they were obtained, it is possible that Pauling would have overleaped Crick and Watson to determine the correct structure. However the share of the Nobel Prize awarded to Maurice Wilkins (Rosalind Franklin having died in 1958) would still have been given for the data.

8. Acknowledgements

The photograph of Professor Mellor (Fig. 1) is reproduced from

<http://www.chemistry.unsw.edu.au/our-school/history-and-alumni/chemical-society/mellor-lectures>

with permission of the copyright holder. The inspiration and information on open science and ELNs for much of the lecture comes from two papers written by Bird and Frey (Bird and Frey, 2013; Bird et al., 2013) and the many papers referenced therein. Fig. 7 is reproduced by kind permission of Dr Katie Pratt. The information in the graphic is based on Emily S. Darling, David Shiffman, Isabelle M. Côté, and Joshua A. Drew, The role of Twitter in the life cycle of a scientific publication, *Ideas in Ecology and Evolution* 6:32-43, 2013.

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