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On the path to improving our teaching – reflection on best practices in teaching chemistry

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Abstract: *The pressures of constantly eroding support and a perception of reduced student intellectual involvement have given rise to a need to evaluate how we teach our first-year chemistry subjects. Students will no longer study what we say just because we say, and so we are forced to reconsider what we teach and why we teach in the way we do. Chemistry laboratories are expensive, time-consuming, and involve inherent safety risks that could be avoided by excluding labs. This paper describes the reflective process our team has followed, with the intent of providing the best possible learning experience, to decide if or how chemistry laboratories are important to the learning of chemistry. The process reported by this group may serve as a generic example of how teachers can reflect on their practice as a team.*

Keywords: *chemistry laboratories; staff development; teaching quality*

The school

Charles Sturt University (CSU) has approximately 30,000 students, only about 20 percent of whom attend on-campus classes at one of the four major campuses in Wagga Wagga, Bathurst, Albury, and Goulburn. The remainder of the students attend classes in either distance education mode (DE) or offshore tutorial mode; in our chemistry classes such DE students are required to attend residential schools, wherein they live on campus and attend intensive three or four day laboratory sessions. Such sessions may also include lectures, demonstrations, and tutorials. First-year enrolments are typically about 65 percent internal students, while the upper division classes are delivered entirely by distance. Students enrolled in chemistry subjects pursue a wide range of courses of study – e.g., pharmacy, agriculture, wine science, food science, environmental science, analytical chemistry, medical science, biotechnology, nutrition and dietetics, teaching, and viticulture.

The problem

The authors make up the six chemistry academics at the main Wagga Wagga campus of CSU, and four others who are involved in facilitating and providing an educational perspective to the project, as well as experiencing the process and replicating it in other Schools. We come from a variety of backgrounds and experiences – from a full professor, to a recently appointed lecturer with no prior teaching experience. As a group we found ourselves frustrated with the decrease in support for our teaching and a perception of decreased student responsibility for their learning. We decided to begin a long-term project to examine our chemistry classes, and to study how we teach, what we teach, and why we teach it.

We were fortunate to get some initial support from the University in the form of Gail Wilson (involved in Organisational Development) and Malcolm Pettigrove (contracted presenter of workshops on documentation of teaching effectiveness) at CSU. Malcolm prepared some primers on the process we might follow, resources on student learning, and acted as a facilitator to help us discover how a process of action research occurs.

There was initially considerable confusion over what the focus and process of this project would entail. Some thought we would cover different ways to team teach a subject; others had a bigger picture view including:

- establishing connections between all the chemistry subjects;
- articulating student learning goals for all classes, and progressively organising to those goals;
- exploring connections between concepts to be taught in the classes; and
- evaluating key curriculum components.

Team members completed a worksheet on our preferred types of teaching (devised by Malcolm Pettigrove – Espoused Values and Values in Action); this worksheet allowed us to critically examine our preferred teaching methods and structures. Brainstorming groups then tried to come up with one topic on which we could focus over the next six months. Several ideas were proposed:

- Focussing on a particular group of students:
- BSc and upper division students: our 'special' students who study to become chemists. Can we find a way to enhance their learning experience – e.g., through mentoring, or greater sharing and spreading of our enthusiasm and motivation?
- Introductory students. This group is perceived to need more attention.
- Mode of study. Parity between the DE and internal student experiences was considered, as was the convergence of how we handle (and the things we expect from) the two modes and diverse learner needs. Internal students are perceived to have a better learning experience, but the DE students do well anyway. This better performance may be due to greater maturity and motivation on the part of the DE students, many of whom are older and more experienced than the typical internal students, and that they are forced to assemble their own understanding of the material, and so learn it better. DE students have been observed to improve the academic level of internal students after mixing; what can we do to improve the experience of DE students?
- Problem solving. Throughout all chemistry subjects, problem solving is a vital skill, and may be the reason many students are required to take chemistry classes.
- "Seminars" as a mechanism to develop key learning and skills in class assessments, both for internal and DE students.

- Forums. The effectiveness of online discussion forums, the predominant online communication medium for students at CSU.
- Laboratories. Examination of why we have labs, whether we accomplish those goals by providing labs, and what alternatives exist.

After some lengthy discussion an articulation of the central theme for the project was decided upon: **How can we give the best possible learning experience to all chemistry students?** Over several weeks the team members individually split up subsets of this question and began discussions of the importance of these issues. We also reflected on these issues with respect to the *HERDSA prompts for good practice* (1992) and the Australian Vice Chancellor's Committee's *Guidelines for effective university teaching* (1993).

Narrowing the scope

After reflection on the results of the first meetings, it became clear that we needed to reduce the number of facets to the problem. It was decided to focus on a single aspect of teaching chemistry – laboratory work. Are chemistry labs important to teaching chemistry? To what aspects of chemical learning do labs contribute? How do labs provide these benefits? What are the teaching staff's and students' impressions of the value of labs?

Laboratories are expensive to operate – demonstration help must be hired, lab chemicals must be purchased and disposed of, instrumentation must be purchased and maintained, technical staff must be employed, and considerable time must be spent marking reports (Sere, 2002). Laboratory learning has also been found in some studies to be less effective than desired (Sere, 2002).

Team members reflected on the desired effects of laboratories, as well as what effects current labs had on student learning; all members considered the desired effects of labs as presented in the Teaching Goals Inventory (Angelo & Cross, 1993). We agreed that, in order to determine the effectiveness of the laboratories, there would need to be some assessment of perceptions. While we may think our laboratories fulfil the desired effects, are the students experiencing those effects as well? For example, why do students think they do labs?

Refining the reasons for laboratory

Outside expectations

A vast majority of the students in our first-year chemistry classes major in other disciplines outside chemistry. A survey was developed for the coordinators of the different courses of study served by these first year classes. Coordinators were asked:

- What skills and knowledge do you expect your students to derive from their Chemistry subject?
- How is chemistry integrated into your course?
- What specific chemical content do your students require from their chemistry subjects to succeed in your course?

Part of the reason for the survey was to try and ascertain whether or not the course coordinators saw chemistry as a valuable component of their course or as a subject that has merely always been part of the course; another reason was to determine outside expectations. We believed that a student's perception of first-year chemistry could be influenced by the value that a course coordinator placed on the subject.

The responses were quite illuminating. The most detailed response came from the Wine Science coordinator and previous experience has shown us that wine science students very clearly understand the importance of chemistry in their course. Responses from courses such as Agriculture and Nutrition and Dietetics were more general; experience with these students indicates that they do not particularly see the relevance of chemistry. Course coordinators in the life-sciences put emphasis on chemistry as a basis for later studies in biochemistry. This presents some difficult issues in that the relevance of chemistry fundamentals seems remote to students still in their first year. We recognise that the perceived lack of relevance is likely to lead students to a superficial approach to the subject matter, where they focus on passing rather than on understanding (Biggs, 1999).

The common responses were focussed more on specific chemical knowledge (often closely course related) than generic skills/attributes. All coordinators believed that laboratories were important to their students' studies.

Our expectations

At the outset of this project, the opinions of the members were widely dispersed regarding the purpose and value of labs. Several members believed labs should be deleted from the first year classes, and only continued in the upper level classes; others felt that labs were vitally important, but that the underlying pedagogy supporting the use of labs in chemistry education needed to be challenged.

We engaged in a brainstorming session to list why we run labs. The results were as follows:

- illustrate theory
- develop problem solving skills
- develop manipulative skills
- lead topics for class discussion
- enhance appreciation of theory
- expose students to important, relevant and interesting examples
- verify principles
- develop record keeping abilities
- pique curiosity
- utilise chemistry tools to solve problems
- train in making observations
- observe chemistry in action
- familiarise with properties of compounds
- stimulate interest
- enhance written and oral communication

There were many differences of opinion about the importance of some of these ideas. A few examples of comments were:

> "Labs provide the unique opportunity for us to shape students' ability to solve problems"
>
> "I am not concerned about lab illustrating lecture topics … the aims of lab are different than the aims of lecture"
>
> "Labs are the environment in which students can be truly active learners due to the necessary level of participation"
> " I consider lab to be an intrinsic part to chemistry education"
>
> "As the vast majority of students doing chemistry subjects are not wishing to become chemists, it is educationally still effective enough for such students to be directed into a 'virtual prac stream' which uses only quick, cheap, but still valuable, computer simulations (especially at first-year level), which serve the purpose of

consolidating/reinforcing the theory. For these students lab skills will not be important for their future…"

"The lab component needs to be done when the topic is covered in lectures; this is possible with internals but given the time constraints and the fact that the lab sessions are either held during the middle of the subject or at the end it is not possible to align lectures and labs, especially for DE students."

"It is important to address the needs of first year students versus subsequent years. A lot of students do first year chemistry but never do any more. Is it important to develop lab skills in these students? Considering the time required and equipment needed I think the available time could be much better spent with demonstrations, computer based activities, problem solving and very importantly showing where chemistry fits in the scheme of things."

It was decided that we should start by focussing on identifying 'what we do now'. A set of 'core ideals' to describe the desired outcomes for laboratories was adapted from the Education Analysis section of the APCELL template (APCELL, 2002), as shown below.

Table 1: Core ideals for laboratory outcomes

	Theoretical and conceptual knowledge		**Generic skills**
1	Clarifying and illustrating theory	15	Academic culture and ethical behaviour
2	Pique curiosity and stimulate interest	16	Knowledge skills
3	Connect chemistry to real world experience	17	Problem solving
		18	Working with others
	Scientific and practical skills	19	Leadership
4	Observe, record and report	20	Critical analysis
5	Interpret findings	21	Computer skills
6	Deductive reasoning	22	Self and time management
7	Apply statistical tests	23	Correct use of references
8	Error analysis		
9	Form hypothesis and test experimentally		
10	Develop manipulative skills		
11	Correct instrument usage		
12	Trouble-shoot laboratory procedures		
13	Develop safe laboratory skills		
14	Presentation of data		

The APCELL source (APCELL, 2002) has explanatory notes to clarify many of these points; we devised the following additional notes to focus our consideration:

Ideal 3: using real or natural samples, situations, and/or examples relevant to the student's field of study;
Ideal 7: least square analysis, t-test, a working knowledge of means, standard deviation, correlation coefficients, etc.;
Ideal 8: correct use of significant figures and an indication of the error of the measurement; and
Ideal 14: graphing, use of spreadsheets and tables

Each member then selected three core ideals that they thought could only -or best - be achieved in a laboratory learning environment. It was reasoned that these ideals should be the focus of laboratory exercises. This selection exercise was in fact defining why we teach labs and/or what in particular we want to achieve from labs. The results are summarised in Figure 1. Note that several individuals were undecided and selected more than three ideals – they found it difficult to select between some of the choices. It could be argued, however, that some of the ideals are closely tied together. As a group we were surprised and pleased to find how similar our responses were, considering the range of opinions expressed in our discussions.

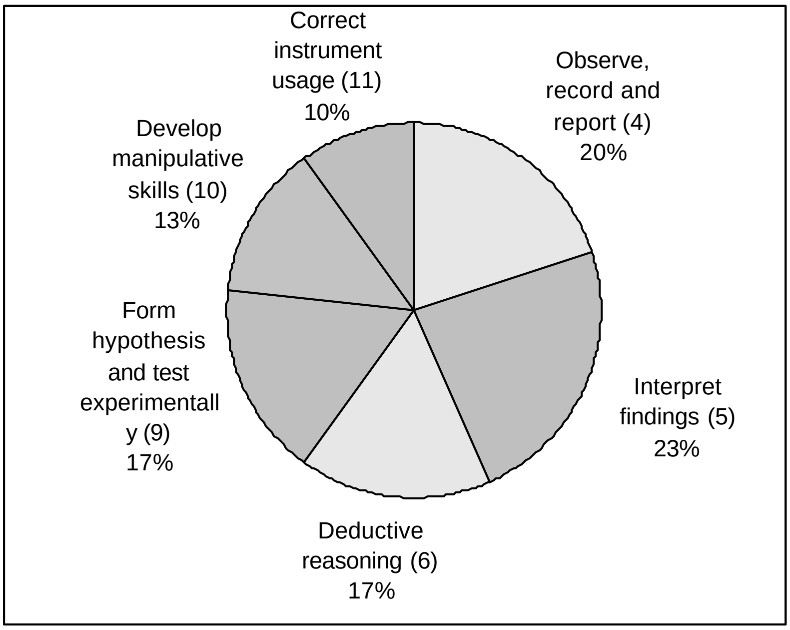

Figure 1: Frequency distribution of core ideals based on APCELL criteria (see Table 1). Only core ideals selected by more than one team member are shown. Ideal numbers in parentheses.

Single selections were made for ideals 1 (illustrating theory), 2 (stimulating interest), 15 (academic behaviour/ethics), 20 (critical analysis) and 22 (time management). The ideals that featured prominently in the combined responses could be seen to fall into distinct groups. Ideals 10 and 11, together selected 7 times, relate to manipulative and instrument use. Clearly labs are a vital means of developing these skills. The higher-level cognitive skills of deductive reasoning, hypothesis formation and testing, represented by ideals 6 and 9, were selected 10 times altogether. It could be argued that these skills may be developed in other chemistry education activities - lectures, tutorials, etc. - as well as in laboratory situations. However, labs were identified as an important means of developing these capabilities. The final grouping combines ideals 4 and 5, which relate to recording, reporting and interpreting observations. These ideals were selected 13 times, and thus seen to be the most important feature of practical lab work.

Discussion was stimulated regarding ideal 9 (form hypothesis and test experimentally): can undergraduates do this? A view was expressed that first-year students need a basic foundation in chemistry before they can be expected to generate their own hypotheses; others argued that when expected to develop an hypothesis, students can develop the skill within a semester. Suggestions were also made regarding ideal 1 (clarifying and illustrating theory): theory can be better demonstrated elsewhere, e.g., as part of lecture demonstrations, yet others proposed that while illustrating theory was an important aspect of laboratory learning, it may not be considered 'core', since alternative forums exist where this objective may be achieved.

Each chemist then selected and evaluated a current lab with respect to the core ideals. Mixed results were obtained, as some selected labs they thought to be poor, and others labs they considered to be very good. This careful reflection on the core ideals in laboratories, and examination of particular labs, led to an unexpected result: all team members but one now agreed that laboratories should be taught in first year chemistry classes – as long as labs incorporated the skills, goals, and ideals we had identified. The dissenter made three basic arguments against first year labs: 1) Explanation/illustration of concepts should be done in lockstep with lecture, and this does not happen even with internal students; distance mode students are even more disadvantaged. 2) Observation, recording, interpreting and drawing conclusions occur in the students' other subjects, and can be achieved in chemistry by in-class methods. 3) Developing chemistry laboratory skills is not important for most students (since over 90 percent of first-year students will learn the lab skills necessary in their chosen discipline subjects); the chemistry students will benefit from upper division classes with more intensive labs and less students.

Student perceptions

Considerable discussion followed regarding whether the students' perception of laboratory learning and that of the chemistry staff match. In addition to the indications from research on this topic (e.g., see Sere, et al., 2001), many of the team had substantial anecdotal evidence relating to the ability of students to competently complete labs, with minimal consistent sophisticated knowledge of the chemical principles or intellectual activity that the lab had been designed to examine. We may develop what we believe to be the best lab in the world, but if the students do not understand the rationale behind the lab format, then much of the value of the lab may be wasted. This gave rise to a series of survey and focus group questions now being used to evaluate student perceptions of the meaning, utility, and value of chemistry labs. The results are currently being analysed and interpreted.

Reflecting on our process

Reviewing our process, we have seen a number of facets in the literature that reflect our experience. We are only in the first stages of action research, in relation to implementing major changes for our students. Possibly, we have drawn an advantage by placing less emphasis on pedagogical theory at the beginning of our project. This has allowed us to more truly define our project in relation to our own conceptions and situation. We may have avoided the "privileging of the perspectives of professional researchers" over the perspectives of ordinary participants (Kemmis & McTaggart, 2000, abstract). As McKernan (1996, p. 31) states, "action research uses the language of everyday discourse employed by the participants" and "group members require a project definition of a problem that appeals to their professional experience" (p. 231). By focusing on and developing our own language and definitions, we have developed ownership of the group and are using a language that is more accessible to others who have not developed “methodological sophistication” (Kemmis & McTaggart, 2000, 'Reconciling different traditions in the study of practice' section, para. 23).

We believe there is value in treating our process as “an act of scholarship that others can critique and build on” (Cox, 2001, 'Teaching as a science' section, paragraph one, quoting L. Shulman, n. d). We can all learn about our learning by subjecting it “to the scrutiny of critical public review” (Bawden, 1991, p. 14). Webb (1998) and Kemmis and McTaggart (2000) write of action research focusing on overcoming or reducing social inequalities in participants’ practice. We have not taken our project to the level of critical social inquiry, but we feel affirmed by the statements: “The criterion of success is not whether participants have followed the [action research] steps faithfully, but whether they have a strong and authentic sense of development and evolution in their practices” (Kemmis & McTaggart, 2000, 'Key features of participatory action research' section, para. 2); and “the act of participation is itself an outcome” (Kember, 1998, p. 10). We would encourage others who have commitment, but feel they lack pedagogical sophistication, to start on a collaborative action research project to improve their practice.

A generic process

We should emphasise that several months were spent coming to a consensus on what we would actually do; a large variety of issues and topics were discussed. We would then muse individually and come back together again with the realisation that the scope was still too broad to be addressed within our time and resource constraints. This process was repeated until a single, manageable topic was distilled.

Meeting as a team forced our reflection to progress; the daily details of academic life too easily distract and sideline considerations of what we teach and why. As a group, we found that a momentum developed in our meetings – the interaction stimulated ideas that at times lead in unexpected directions. Without question, the synergy that evolved helped to reveal our individual biases and preferences. By exposing these biases, we were able to extract and examine the most important issues for us as educators. For example, one member’s persistent view that labs have little value compared to the cost in time, materials and energy, continually forced the team to question and defend conducting labs. Such determined reflection and reappraisal of one’s opinions could not occur otherwise.

The process pursued by this group may serve as an example of how other teachers can reflect on their practice as a team. The process has proved to be far more involved and difficult than the participants ever imagined. We have formulated some guiding thoughts:

- Discuss the big ideas at length;
- Narrow down the range of ideas to a single, manageable theme;
- Realize that you will likely need expertise from outside your discipline;
- Question what you were taught and why;
- Reduce to first principles the reason for teaching a theme – what is the desired outcome in student learning?
- Assess how the theme is now taught with respect to the desired student outcomes;
- Assess whether the students are achieving the desired outcomes;
- Change the process of teaching; and
- Reassess whether the students are achieving the desired outcomes.

Where to now?

The reflective process our group has begun has given us a basis for ongoing examination of the way we teach chemistry. The process has led us to a better understanding of the value and relevance of laboratories in the learning of chemistry. We can now tackle the pedagogical issues, and the pressures and conflicting demands upon us, as a team.

This project has led to changes in our teaching – already for 2003 new labs have been introduced that are more closely aligned to our core ideals. Even without complete consensus among team members, we were able to make some progress towards our goal of providing a better learning experience to all chemistry students.

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