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PG Cert in University Teaching – Understanding learning and studying assignment

Student Learning and Studying: The Chemistry 1 Course

Background information – Chemistry 1

- This course is designed to take students with diverse backgrounds and provide them with the thorough grounding in the fundamentals of chemistry that they will require in subsequent years and also provide a basic training in the essential skills of practical chemistry.
- Contact teaching time is 7 hours per week for 11 weeks in Semesters 1 and 2.
- Tutorials - 1 hour per week. Associated weekly assignments are computer exercise based or written exercise based.
- Laboratory classes - 3 hours per week.
- During week 8 there is a computer based multiple choice test.
- The course has a website where students can find useful information about the course and about studying at Edinburgh University. Students can also give feedback on the course.
- Entry requirements: SQA Highers - 4 B's, GCE A-levels - 3 B's in chemistry and maths, plus physics or biology. The equivalent is necessary for international students.
- Students with special requirements are catered for. The course meets all requirements (and addresses the 2006 amendments) to the Disability Discrimination Act, i.e. nowhere is it suggested, directly or indirectly, that the success of an application depends on not having a disability or that adjustments would not be forthcoming.

*I am a Research Fellow from the School of GeoSciences. My discipline is environmental chemistry and I did my undergraduate degree and part of my PhD research at the University of Edinburgh's School of Chemistry. I am not teaching on this course but I undertook this course (as it was ten years ago) and was a laboratory demonstrator for this course during my PhD, from 2002 to 2006.

This piece of writing contains a set of guidelines alerting the first-year Chemistry 1 course team to likely differences between Chemistry 1 students in how they learn and understand the same phenomenon, solve problem and learn from laboratory classes. Ways of encouraging Chemistry 1 students to use cognitive processes will also be discussed and suggestions as to how teaching-learning practices in Chemistry 1 could be enhanced will be made.

1. Differences between Chemistry 1 students in the way they learn and understand the same phenomenon.

Lybeck *et al*., (1988) adopted the 'phenomenography' research approach, which involves the study of the qualitatively different ways in which people experience and conceptualize the world around them. These workers studied students' differing conceptualizations of the 'mole concept' – a fundamental concept used in chemistry which is taught at school. Thirty science students (aged 16-19, 9 girls, 21 boys), from a Swedish secondary school were interviewed while they undertook a task. The task involved looking at three groups of three plexiglas cylinders which contained tin, aluminium or sulfur. The students were asked 'Which group of cylinders contains 1 mol of each element'. The principle of the task was as follows: in group I, the amount of substance is constant i.e. 1 mol of each element. In group II the volume is constant and in group III, the mass is constant. During the interviews students were asked to explain their answers and their thought processes were probed. Lybeck *et al* examined the way students handled this task in order to derive a structure from the way in which they dealt with that task.

Lybeck *et al*.'s work revealed that the students they studied all used combinations of a limited set of concepts and relations. The main strategy that students used to answer the task was to thematize the task from a continuous or from a discontinuous perspective. Within the context of chemistry, macroscopic observations (i.e. colour change) correspond to a continuous perspective on matter and the microscopic model of explanation corresponds to a discontinuous perspective on matter. Two groups of students took a surface approach to learning, the first group pursuing a continuity-type line of reasoning with the help of continuous quantities such as mass, volume and density. The second group pursuing a discontinuity-type line of reasoning with the help of the quantity number. A third group of students took a deep approach to learning and co-ordinated both the continuous and discontinuous aspects of the problem in their line of reasoning. Lybeck *et al*. (1988) suggested that the students' answers reflected different conceptions of matter. Firstly, a continuous perspective concerned 'compaction of the solids, grain size etc'. Secondly, a discontinuous perspective contained thoughts about the atoms compaction and volume. Many students had problems in combining continuity with discontinuity i.e. the real, visible world with the explanatory model. They also found that there were quantitatively different ways of conceptualising what a 'mole' was. Students which took a surface approach understood the 'mole' as (i) something that was used in calculations, with little reference to the real world, (ii) something as being identical to mass, (iii) something that was dealt with as a number. In contrast, students that took a deep approach understood the mole as something related to number and mass. To answer the task correctly, students had to use both a continuous and discontinuous framework.

To make the 'mole' concept clearer to students, Lybeck *et al.* (1988) suggested the introduction of molar mass tables in text books because the use of the periodic table as a molar mass table makes it difficult for students to understand the 'mole' concept. Lybeck *et al*., (1988) also suggested the use of relationship equations to avoid 'muddiness' in text books.

The 'mole' concept is not taught in Chemistry 1 because this is something students learn at school. Also, Lybeck *et al.*'s work was undertaken using secondary school students, so their work is not directly relevant to the way students learn and understand phenomenon in Chemistry 1. It could be helpful, however, to hand out molar mass tables and a list of relationship equations to students at the start of the course. This would help bring students who, even after finishing school, are confused by the 'mole' concept, to the same level as those who already have a clear understanding of it. Also, as part of Chemistry 1, to address Lybeck *et al.*'s finding that many students have problems combining the real, visible world with the explanatory models, it may be useful for lecturers to use plenty of examples which link the theoretical material that they are presenting with real world situations.

2. Differences between Chemistry 1 students in the way they solve problems.

The Dreyfus model of skill acquisition states that a person moves through five stages on a path from novice to expert performance. In the context of chemistry, at the novice stage, where most Chemistry 1 students are, students recognize objective facts and features relevant to the skill required to become a chemist. Novices rely on 'context-free' rules to help them solve problems and they judge their performance by how well they follow these learned rules (McLoughlin and Hollingworth, 2005). Chemistry 1 students who completed A-levels or Advanced Highers at school may be more advanced and experienced than students who have only completed Highers.

According to Dreyfus's model, these more experienced students may be able to recognize situational elements as well as context-free components because their experience allows them to see similarities to previous examples they have encountered (McLoughlin and Hollingworth, 2005). On the other hand, Access students enrolling in Chemistry 1 may find it more difficult, compared to 'fresh' school leavers, to recognise objective facts and features relevant to the skill because they have been out of education for a long time.

When solving real problems students typically make a decision quickly and pursue that direction no matter what (McLoughlin and Hollingworth, 2005). In contrast, an expert spends a large part of the time analyzing the problem and exploring possible solutions in a structured manner. McLoughlin and Hollingworth (2005) found that students cannot learn essential skills through short-term instruction or through teaching approaches that focus only on content and finding the solution to the problem. They suggested that teachers expose their students to verbal explanations of problem solving. This process-based approach to teaching, if employed consistently with students, gives them the benefit of witnessing and observing expertise in problem solving. Chemistry 1 lecturers could be encouraged to 'think aloud' as they solve problems in front of students. The main drawback to this approach, however, is that some lecturers may not want to change their style of teaching or may be hesitant about exposing themselves in this way. To overcome this drawback, 'hesitant' lecturers could practice using this approach during tutorials, where there are smaller groups of students. This would be less intimidating than using the approach for the first time in front of a lecture theatre full of students.

McLoughlin and Hollingworth (2005) also suggested that experts could share their expertise with novices by focusing on developing self-knowledge among learners. Self-knowledge is an important dimension of meta-cognition and it can be supported by things such as getting students to compare their strategies with those used by other students, encouraging students to assess their success prior to undertaking the task and question their motivation for the task. In Chemistry 1, self-knowledge could be encouraged by getting groups of students to discuss how they would each go about solving a problem, whether they each think they will be successful and what their motivation for solving the problem is. To an extent, this self-knowledge process is already practiced as part of the Chemistry 1 laboratory classes but encouraging students to assess their ability and motivation to solve problems would be useful.

McLoughlin and Hollingworth (2005) considered two simple problems which might be given to students in first year university science. To solve the first problem, all students needed to do were insert data into a formula to obtain the right answer without much thought. The second problem, however, needed transfer of skill to a novel situation. Students needed to search for extra data and many students found it initially difficult to understand what the question was about. McLoughlin and Hollingworth (2005) recommended that teachers ensure that their students are exposed to a range of problems, from simple to complex and from well-defined to ill-defined. In Chemistry 1, this recommendation is already fulfilled by the tutorial questions that students are given. The questions get progressively more challenging and always include a mixture of routine problems, applications of formulas, conceptual questions and challenging problems. With the provision of this range of questions, Chemistry 1 is attuned to it's cohort of students.

3. Differences between Chemistry 1 students in the way they learn from laboratory classes.

One of the most important purposes of laboratory work is to enhance the learning of scientific knowledge. Gorst and Lee (2005) argue that teaching approaches to undergraduate laboratories often fail to convey the right messages or excite the students. They argue that the large laboratory class sizes, limited equipment and timetable scheduling do not encourage scientific exploration. With each experiment, students are challenged not only by the problem being presented but also by issues such as how to set up and use the apparatus, how to collect and interpret the data and how to write up the experiment. With so much to think about, the students end up using poor pedagogical coping strategies such as copying others and following instructions without thought.

Gorst and Lee (2005) suggested that supplementary nonlaboratory activities may help to bring about conceptual development. The Chemistry 1 course does not provide any nonlaboratory activities but inclusion of a trip to a local chemical company could be extremely useful and motivating for students. Available time and staff are major constraints to this but an alternative option could be to show students a

DVD explaining what happens in the laboratories of chemical companies. Also, to overcome time constraints, the footage could be made available on the course website.

Gorst and Lee (2005) also suggested that the use of computer simulations can aid students' appreciation of scientific literacy to a degree not possible in traditional laboratory work. In Chemistry 1, computer simulations are used in some of the weekly assignments.

It is important that laboratory classes help students to link the concepts that they learn during lectures with the practical work they undertake (Gorst and Lee, 2005). In Chemistry 1, lectures and laboratory classes are structured and timed in a way that materials taught in lectures are tied in as much as possible with relevant laboratory classes. To improve student learning, however, it could be helpful if lecturers told students which specific parts of their lecture materials were of relevance to that week's laboratory class. This could help the students understand what is expected of them academically.

The terms *reproductive practice* and *transformative practice* have been used to describe methods by which students learn. At the lowest level of inquiry, the problem to be investigated, the apparatus to be used, the procedure and the answer to the problem are all given to the students by the teacher. This is termed reproductive practice, in which complex methods and ideas of a discipline are reduced to routine practice via convergent thinking. At the highest level of inquiry, student-centred learning is at the core and students are required to determine all of the outcomes for themselves (Gorst and Lee, 2005). Reproductive practice is used in the Chemistry 1 laboratory classes (e.g. the laboratory manual tells students what to do) and students don't usually get to use more transformative practice until their 2^{nd} year of study. The use of more open inquiry in Chemistry 1 is difficult, however, because of time constraints and safety management problems. It is also unrealistic given the different levels of practical skills and experience within the Chemistry 1 student cohort.

The presage-process-product model proposed by Prosser and Trigwell (1999) considers perceptions of learning as an interaction between previous experiences of learning (presage), the learning context and the students' approach to learning (process), and the students' learning outcomes (product). Gorst and Lee (2005) studied third-year biology students at an Australian University to illustrate that there is diversity in what students bring to laboratory work, what they perceive to be the reasons for and relevance of laboratory work, how they learn, and what learning difficulties they have. Students were presented with some of the factors in the presage-process-product model in questionnaires or through interviews. Gorst and Lee (2005) conducted two surveys of the third-year biology class (66 students). The first survey, conducted before the laboratory work began, probed the students' background, their attitudes about laboratory work, their expectations of the course, the perceived relevance of the course to their future aspirations, and how they would prepare for each laboratory class. The second survey, conducted in the final revision week, asked about the students' enjoyment of the course, what they had learned, how they learned practical work, their preparation for laboratory classes, and which particular parts of the laboratory work had presented learning difficulties. Taped interviews were also conducted using five students. These students had differing attitudes towards laboratory work and consisted of two males and three females. One of the students was a mature-age student.

Presage - Findings from the first class survey revealed that 40 % of the students had negative feelings toward laboratory work, 70 % of which were unenthusiastic about designing and carrying out their own experiments. Of the students that were looking forward to laboratory work, 86 % were also looking forward to some independence in the laboratory. The latter students reflected higher-order attitudes toward learning and a desire to take control of their own learning.

Process - The perceived relevance of what the students were doing in the laboratory classes was a major factor in stimulating student interest in the course. It was also found that students who had already decided on their career paths could be unwilling learners if the laboratory work was not directly of use to those paths. Unfortunately this problem is difficult to resolve but it is worth noting that these findings are based on third year students. Most first year students enrolling in Chemistry 1 will not have decided their career paths.

Findings from the interviews revealed that all five students used deep learning approaches to some extent but they also expressed the view that learning in the early undergraduate years was based on memorizing facts. Learning in the Chemistry 1 course is based on memorizing facts but this is vital because the main aim of the course is to get students with diverse backgrounds to the same level of understanding.

Findings from Gorst and Lee's study also revealed that the major pathway students used to learn practical work was via asking someone perceived to be knowledgeable. Teachers telling students too much during laboratory classes was suggested to be partly responsible for the failure of students to meaningfully learn and retain information. Chemistry 1 demonstrators are encouraged not to 'tell students the answers' but this could be re-enforced in their compulsory training courses.

Reading the laboratory manual was also nominated as a major learning pathway but only 54 % of the students claimed to have read the manual 80 to 100 percent of the time prior to a laboratory class. Based on these findings, Chemistry 1 student learning could be improved by getting demonstrators to give students a briefing about that days experiment before the practical work starts.

Active, deep learning fostered by a more open-ended approach to laboratory work is thought to be enhanced by group interaction, something which is encouraged in Chemistry 1. However, it was found that some groups divided up the work so that they could finish class early (Gorst and Lee, 2005). This happens in Chemistry 1 laboratory classes but it is difficult to prevent given the large class sizes.

Gorst and Lee's study revealed that conceptual aspects of laboratory work presented students with some learning difficulties. To overcome these difficulties, students asked the demonstrators to explain or spoke to their classmates. In Chemistry 1 laboratory classes, students also have demonstrators and classmates at hand but as an additional aid to learning, textbooks could be available in the laboratory for students to read.

Product - A practical exam was used to assess the students that Gorst and Lee studied. This exam tested student understanding and focused on deep learning and application. Strategies used by students to study for this exam included doing nothing and revising laboratory notes. The student's exam marks were generally good. These findings indicate that the students had different levels of confidence and/or perceptions of what was expected of them academically. These findings are of little relevance to Chemistry 1 students because their laboratory work is assessed through their experimental write-ups and performance in the classes alone. Based on my own experience, some students do not take laboratory class assessments as seriously as examination assessments. The introduction of a practical examination could solve this problem but would mean extra scheduled laboratory sessions which are expensive.

4. Encouraging Chemistry 1 students to use cognitive processes

Heerden (2005) described the following cognitive processes at the heart of chemistry: (i) considering structure to explain properties, (ii) seeking patterns, (iii) using models, (iv) developing a specialized vocabulary, (v) understanding that numbers are relative to a context and (vi) connecting abstractions with real-world experiences. First year students often fail to use these cognitive processes because they have not learned how to think like chemists yet (Heerden, 2005).

Heerden (2005) encourages her students to consider structure by asking them to explain why the properties of H_2, O_2 and N_2 varied significantly. When students ask for direction, she tells them to consider structures. If students need further direction she gives them more suggestions, one at a time. This way of teaching would be particularly useful to Chemistry 1 because students cannot rely on memorized information but must really analyse the molecules.

To encourage students to look for patterns, Heerden (2005) asks her students questions which probe their understanding of data they have obtained in laboratory classes. She also assigns students with independent laboratory projects. The former approach could easily be adopted in Chemistry 1 but the latter approach is unrealistic because of time constraints and safety management problems (as mentioned in point 3 above).

Heerden (2005) gets her students to use models by getting them to watch a video that provides information about a variety of different chemical models. At the start of the Chemistry 1 course, students are given molecule kits which are extremely useful because they allow them to visualise 3D models of the molecules they are studying.

Students can develop a specialized vocabulary by exposing them to words used by chemists and increasing their experiences of working with these words (Heerden, 2005). Chemistry 1 students are constantly exposed to this specialized vocabulary.

To teach students to understand that numbers are relative, Heerden (2005) sets assignment questions that get students to think more deeply about their numerical answers. This approach is also used in Chemistry 1 tutorial and laboratory class assignments.

Heerden (2005) helps her students to move between abstract ideas and real-world experiences by getting them to imagine everyday processes when describing chemical concepts. In Chemistry 1, lecturers should be encouraged to adopt this approach by making as many references as possible to real-world experiences (as mentioned in point 1 above).

In conclusion, the current research literature has helped me to produce guidelines and suggestions as to how teaching-learning practices in Chemistry 1 could be enhanced. There are strengths and weaknesses in the different forms of student learning research discussed here. I believe that Lybeck's phenomenography approach is particularly useful because studying students understanding of conceptions in chemistry should contribute to conceptual development in chemistry itself. I also agree that one's own understanding of chemistry has to be used in order to grasp the students' ideas in depth and to relate them to each other. I found the process-based problem-solving approach suggested by McLoughlin and Hollingworth convincing because it is likely to assist students to actively develop problem-solving skills and discuss and explore their understanding. I thought some of Gorst and Lee's criticisms of undergraduate laboratory classes were too harsh and their ideas were sometimes unrealistic and largely based on third year biology students. These workers arguments could be strengthened if they were to investigate more students, particularly first year students. I also found Heerden's advice convincing because she was speaking from experience as a practising chemistry lecturer. In the future, I would like to adopt some of her new modern ways of teaching in my own teaching style.

References

Chemistry 1 course website http://www.ed.chem.ed.ac.uk/teaching/chem1/index.html

Gorst, J. and Lee, S. (2005). ‘The undergraduate life sciences laboratory: student expectations, approaches to learning and implications for teaching.’ In: McLoughlin, C. and Taji, A., eds. *Teaching in the Sciences: Learner-Centred Approaches.* New York: Food Products Press/Haworth Press. pp. 43-62.

Lybeck, L., Marton, F., Strömdahl, H. and Tulberg, A. (1988). ‘The phenomenography of the ‘mole concept’ in chemistry.’ In: Ramsden, P., ed. *Improving Learning: New Perspectives*. London: Kogan Page. pp. 81-108.

McLoughlin, C. and Hollingswort, R. W. (2005). ‘Problem-solving in the sciences: sharing expertise with students.’ In: McLoughlin, C. and Taji, A., eds. *Teaching in the Sciences: Learner-Centred Approaches.* New York: Food Products Press/Haworth Press. pp. 105-121.

Prosser, M. and Trigwell, K. (1999). *Understanding Learning and Teaching: The Experience in Higher Education*. Buckingham, Society for Research into Higher Education and Open University Press.

Heerden, A. van. (2005). ‘Articulating the processes at the heart of chemistry’. In: Riordan, T. and Roth, J., eds, *Disciplines as Frameworks for Learning: Teaching the Practice of the Disciplines.* Sterling, VA: Stylus. pp. 95-120.