place in analytical chemistry today. To show the tunnel effect through a barrier between two metals, Binnig and Rohrer provided a thought experience in their 1982 patent, filed with the United States Patent Office (G. Binnig, & H. Rohrer: 1982, 'United States Patent: Scanning Tunneling Microscope, August 10, 1982', Assignee: International Business Machines Corporation, Armonk, NY. Patent Number: 4,343,993, figure 1, sheet 1). The design plans for scanning tunneling microscopes by Binnig and Rohrer offer readers a model of electron tunneling. From the perspective of energetics, the electron travels to a surface atom by tunneling *through, but not over*, the energy barrier (G. Binnig & H. Rohrer: 1985, 'The Scanning Tunneling Microscope', *Scientific American*, August, pp. 50-56). Readers are often convinced via these plans that they *could* reproduce the same processes, as if they could re-enact significant features of the experiment. Underlying the rhetorical function of such design plans are models of quantum mechanics, offering chemists a justification for adopting revolutionary instruments, and a basis for profound changes in research techniques.

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Teaching Philosophy of Chemistry at the University of Exeter

Teaching an undergraduate course in Philosophy of Chemistry to chemists provides many challenges since few academic subjects are more different in their way of thinking (*e.g.* their approach toward truth, their language, formalism), teaching and, communication style. In October 1999 the School of Chemistry at the University of Exeter (UK) has introduced an optional course in 'History and Philosophy of Chemistry' for 2nd and 3rd year chemistry undergraduates. This course has since been growing in popularity among students and its philosophical component now consists of 11 lectures with additional 40 hours associated study-time for revision and background reading. The curriculum has also been continuously updated to provide students with philosophical concepts relevant to – and also exemplified by – chemistry.

The current syllabus addresses three philosophical topics: theory of science, logic of arguments, and ethics. The first part covers basic concepts of epistemology such as scientific reduction, scientific versus logical truth, verification, falsification, and methods of scientific inference (induction and deduction). The second part discusses the systematic logical analysis of chemical reasoning, a technique that complements the traditional literature review students already undertake in chemistry. The ethics section introduces the concept of responsibility, explains utilitarian and normative approaches toward chemical research (*e.g.* chemical weapons research and medical drug design, testing of chemicals, and distribution of resources). It also illustrates Kant's categorical imperative in moral conflict situations and looks at the role of casuistic learning of 'ethical behavior' during practicals, case studies, and undergraduate research projects. Although there is no specific textbook for this course, basic philosophical literature, some of which even uses ex-

amples from chemistry (*e.g.* W. Hodges 'Logic' and H.C. Byerly's 'A primer of Logic') is used. The 'Ethics of Chemistry' issue of *Hyle* (Vol. 7, 2001) provides the basis for the discussion of ethical aspects relevant to chemistry.

In order to evaluate the impact / success of this course, three indicators are considered here: a subjective report by one of the students, a brief presentation of a student questionnaire and an assessment by the course coordinator. First, a look at a 3rd year student's comments (Glenn Jones).

"I think the aim of the course was not so much to agree or disagree but rather to stimulate a thought process, to look at one's actions and consequences as a chemist, to raise 'awareness' of our work. The lectures challenged our idea of what a chemical is, when a chemical becomes a chemical and discussed the idea of the chemist altering the physical world, for good or ill. This course is interesting and stimulates a whole new thought process not usually encountered in undergraduate chemistry. So far I have found its use to my chemical work limited, that is not to say I cannot foresee situations where it could prove beneficial. I have also found that my communication skills and ability to manipulate and understand non-subject specific arguments have improved. I have a feeling that many of the points that have been raised would be considered by any good student – and should a group of good students gather late at night in the bar, they would have a discourse on such topics, although they may not remember! What the course does do is to formalize many familiar ideas and try to structure them in a way that allows repeatable communication. I find the presentation of the course novel, it is not everyday you get to talk to or question your lecturer in a chemistry lecture, but this also has its downside as shy or quiet people who may have excellent thoughts can get alienated. I feel it would be beneficial to write about the topics covered as it gives time for deeper reflection and allows the construction of points that can't be done in a quick-fire environment. Overall the course was interesting and thought-provoking and enabled reflection on areas that are not formally tackled in other lecture courses."

This impression was mostly shared by the other 17 students of the course that were asked to rate aspects of the course on a scale from 1 (worst) to 10 (best). Overall, they rated the course highly (on average 6.5 out of 10), particularly emphasizing its originality (8.5), the benefit of taking a different perspective on chemistry (7.7), the use of logical analysis to better understand the structure of arguments (7.5), and the importance of critical thinking as part of the undergraduate chemistry curriculum (7.0). Students also indicated that they considered their philosophical knowledge prior to the course as minimal (2.9) and a majority thought that the course helped them to better understand how chemistry works (5.7).

These responses indicate that teaching philosophy of chemistry is equally interesting and beneficial for students. Interesting, because it provides a different way of thinking, new topics, and a distinctive learning style. Beneficial, because it widens students' view of their subject, allows them to look more critical at experiments and theories, and teaches them to discuss rather than repeat concepts. Learning how to communicate (*e.g.* participate in a group discussion, write an essay) is an additional bonus.

From a teacher's point of view, the 'Philosophy of Chemistry' course is a challenge since it breaks with traditional chemistry teaching. It intentionally provokes critical thinking, stimulates the learning of new subjects and requires a specific – for chemistry unconventional – teaching and learning style. For example, students are asked to question concepts they have so far taken for granted and engage in discussions of scientific validity and ethical behavior in the la-

boratory. This clearly breaks with the tradition of learning accepted concepts from textbooks. The content of the course, although tailored to chemistry, also introduces topics from other fields (*e.g.* logic, theory of science, ethics), hence significantly expanding the chemistry syllabus. The combination with History of Chemistry further widens the perspective, and also provides an additional context with plenty of historical examples.

Not surprisingly, the course requires an interactive teaching style where questions from and to the lecturer, discussions, feedback and ad hoc conceptualization play an important role. While students like to be actively involved and later easily remember 'their own' concepts in essay-style examinations, this also provides the lecturer with the opportunity to closely monitor student progress and spot learning difficulties. Although this strongly encourages quieter students, the tradition of a 'quiet audience' is clearly a problem in chemistry teaching that must be more widely addressed in the future.

The lack of a good textbook is unfortunately still a major drawback. Although journals such as *Hyle* are extremely useful, one can only hope for a comprehensive, yet easily understandable textbook for the Philosophy of Chemistry course. Once an accepted curriculum for such a course exists, a suitable textbook will surely follow. In this context, we should point out that the lecture notes for the Exeter course are freely available from the corresponding author on request.

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