Science and the public: Teaching *about* chemistry on university courses

Perspective

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A distinction can be drawn between knowledge *of* chemistry (the facts, concepts and relationships of chemistry, e.g. the structure of benzene, valency, Raoult's law) and knowledge *about* chemistry (the practices of chemistry, e.g. how chemists decide which questions to investigate, how new knowledge claims in chemistry are developed and validated and how disagreements between chemists are resolved). Such knowledge about chemistry is of relevance to all chemistry undergraduate students irrespective of their future employment intentions. Whilst knowledge about chemistry is inevitably an aspect of university chemistry courses, it is suggested that knowledge about chemistry needs to be taught *explicitly* and should be a *recurring* feature of university chemistry teaching.

Science and the public

There is growing interest both in the UK and worldwide in the ways in which science interacts with public policy. The relevance of this issue has been highlighted in recent debates, such as those concerning the safety of foodstuffs derived from genetically modified organisms, whether or not depleted uranium used in warheads might be a cause of leukaemia amongst military personnel and the safety or otherwise of the measles-mumps-rubella (MMR) vaccine. In all these cases appeals have been made to scientists to provide evidence to inform public debate. On the morning I began work on this perspective I had listened to an interviewer on a national radio programme questioning two scientists concerning their work on the toxic and radioactive effects of depleted uranium on humans, an excellent opportunity for contemporary science findings to inform media debate. However, from the listener's point of view, the key feature that emerged from the interviews was that the two scientists disagreed about the conclusions that could be drawn from their work. What is the listener to make of this? Is one of the scientists incompetent or even biased? What the listener, and perhaps also the scientists being interviewed and the interviewer herself, needed was some understanding about how science works, i.e. knowledge *about* science. This needs to be part of people's general understanding about science to enable them to engage in science-related debates as they arise. In the context of the radio interview the listener should be able to appreciate that the question of the impact of depleted uranium on human health is a complex one. Carrying out empirical work in this area using human subjects is not an option. Whilst empirical investigation might involve non-human subjects or *in vitro* studies, such work is open to questions about the validity of extrapolating its results to humans. A retrospective investigation might involve a statistical study of the health of military personnel and relating it to their exposure to depleted uranium. Here issues such as sample size, estimating dosage and the location of exposure in the human body, become important. Also, cases of leukaemia may have occurred as a result of other causes. How can these be distinguished from those that might follow from exposure to depleted uranium? All these considerations involve knowledge about how science works as much as they do technical knowledge of uranium and its physiological effects on humans.

A number of detailed studies[1] have been made of how non-scientists make decisions on issues with a scientific dimension. Examples involving chemistry include local debates about the toxicity of emissions from an industrial site located near to urban housing and the impact and causes of acid rain. As in the depleted uranium case, these studies show that the knowledge important in these issues is not solely, or even significantly, knowledge of the facts of science. It is knowledge *about* science that often plays the most crucial role as scientists, mediators of science, and the public become involved with science as it affects issues of public policy.

Purposes of university chemistry courses

University chemistry courses provide preparation for three broad areas of employment: as professional research chemists; chemistry-related employment in the media, teaching, the commercial sector, or within local or national government; and employment not directly related to chemistry, such as work in business and finance sectors. Where science relates to issues of public interest, such as in the examples given earlier, individuals in all three employment areas may be involved. Research chemists generate new findings and are asked to report on these to their peers, their funders and the public. Science journalists, spokespeople for commercial companies and pressure groups, and science policy makers provide their reactions to the findings of the scientists. Those not professionally involved in science react to the findings by making choices as consumers, protesters and/or voters. In many contexts public response can have a significant impact on the direction of future science research as commercial and governmental organisations react to consumer and voter pressure. In this way all graduate chemists have a role to play in public debates about science. Given the crucial role of knowledge *about* science in such debates, its incorporation into the curriculum would be a service to all chemistry undergraduates.

Additional impacts of knowledge about chemistry

Aside from the science and public policy rationale outlined above, there are additional, perhaps more immediate, reasons for developing students' ideas about how chemistry works. There is growing evidence that encouraging students to think about the structure and purposes of scientific knowledge can support their understanding of science concepts. For example, one study[2] designed and evaluated an upper secondary course that included teaching about the general relationships between theory and phenomena in science alongside the teaching of energy transfer in electrical circuits. For many students an understanding of the nature of scientific knowledge enhanced their ability to apply their developing understanding of the concept of energy in electrical circuits in experimental situations. To my knowledge, the interaction between knowledge about science and science concept learning has yet to be examined within university science courses. By contrast, the interaction between ideas about science and university science students' experiences of investigative work has been examined. A study involving chemistry undergraduates found that naïve views about how data and theoretical models interact in science can act as a barrier to students' progress during investigative project work.[3] It is likely that emphasising knowledge about chemistry within university courses will enhance students' understanding of chemistry concepts and their actions during investigative work.

Knowledge about chemistry in the curriculum

Associated with continuing concern about the nature of the interaction between science and those not professionally involved in science[4, 5] there have been a number of initiatives to emphasise knowledge about science within pre-university science education.[6] For example, the current National Curriculum for Science in England has a new section entitled 'ideas and evidence in science' that focuses on 'how science works'. At the post-16 level there is a new AS course 'Science for Public Understanding';[7] a group supported by the Royal Society has begun investigations towards an AS course on the 'History and Philosophy of Science'; and a project funded by the Nuffield Foundation has recently published materials for teaching about science *within* A level science courses.[8] Similar projects have been pursued outside the UK.[9] Against this background, new entrants to university chemistry courses will increasingly be aware of discussions about how knowledge in chemistry is developed, how disputes in chemistry arise and are resolved and what chemistry knowledge can and cannot contribute in complex problems outside the laboratory whenever chemistry interacts with issues of public concern. In part this article aims to contribute to a debate about whether/how university chemistry courses should respond to these developments.

University students' knowledge about chemistry

It might be said that 'how chemistry works' is addressed already in university courses. Indeed any course that requires students to apply chemical knowledge in problem solving tasks, and to undertake science investigations of their own, is inevitably raising issues of knowledge about chemistry. However, many of the areas in which students are asked to solve problems or conduct chemical investigations are far removed from the ways in which chemistry impacts on public policy. For example, many first and second year courses involve investigations in the laboratory in which the answer is already known and the detailed guidance notes limit the chances of things going wrong. Of course such activities provide a legitimate way of developing students' ability to use established empirical techniques. However, they are unlikely to communicate the uncertainties and complexities of applying chemistry to issues of public concern.

Furthermore, despite the inevitable presence of knowledge about chemistry in university courses, several studies have shown that students often leave university with very naïve views about how science works.[10,11] Many students see science as capable of providing 'hard facts', that it is always possible to obtain data that will provide a single, incontrovertible interpretation. The presence of uncertainty and multiple interpretations, particularly in complex settings, is often not recognised.

Teaching knowledge about chemistry

So how can knowledge about chemistry be communicated within undergraduate courses? The strongest message coming from the few studies that have been conducted to date is that knowledge about how chemistry works needs to be taught *explicitly*. It is rarely sufficient for students to engage in chemical investigations or chemical problem solving activities for them to develop their knowledge about chemistry. For example, we followed the experiences of 11 undergraduate science students (including 2 chemists) as they undertook final year research projects over a period of 8 months.[12] These projects gave students the experience of engaging in authentic research that addressed complex issues. Gathering reliable data was often a real challenge and in most cases only tentative conclusions could be drawn. However, experiencing authentic research was found not to be a sufficient condition for being able to articulate an appropriate view about 'how science works'. Many of these students persisted with their view of science as always involving 'hard facts'.

To make knowledge about chemistry explicit students need to be encouraged to ask questions about the structure, purpose and limitations of chemistry knowledge. How sure can we be about our conclusions? Do our findings enable us to make any generalisations outside the context of the study? What can our laboratory study tell us about the chemistry of materials in contexts outside the laboratory? What additional issues would need to be considered? Are there other possible interpretations of the data? If so, what should chemists do next in order to resolve the dispute? It might be said that add-on courses on the History and Philosophy of Science/Chemistry could serve this function. I would argue that whilst such courses do serve legitimate aims, they are not best placed to develop students' ideas about science with a view to supporting their consideration of public policy issues and their learning of science concepts and investigative activities. The teaching of knowledge about chemistry needs to be an integrated part of a university chemistry course, with discussions about how chemistry works running through lecture courses, problem solving classes, investigative work, and (critically) assessment activities.

Conclusion

Not everyone would agree that a strengthening of knowledge about chemistry within university courses is desirable, particularly given the other pressures on curriculum time. This perspective aims to contribute to a debate about how/whether university chemistry courses should respond to the increasing focus on knowledge about science within pre-university education. Secondly, lecturers themselves have limited experience in explicit teaching about chemistry and few resources are available to support such teaching. This perspective is also a plea for university chemistry teachers who recognise the need for knowledge about chemistry teaching to develop such teaching and to communicate to others what works and what doesn't work and there are signs that this is beginning to happen.[13] Finally, there has been little, if any, research into the impact of knowledge about chemistry teaching on students' ideas about chemistry within university courses. Such studies would provide insights into how students develop new ways of thinking about the practices of chemistry both within chemistry research and also in matters of broad public concern.

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