Coaxing chemists to communicate

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A module *Communicating Chemistry* has been designed and incorporated into the curriculum for the penultimate year of the BSc (hons) Chemistry Course at Heriot-Watt University. The module is taken by a cohort of about 50 students and occupies 100 hours of student effort over an 8 week period. The module consists of 10 exercises each of which is built around a chemical scenario and engages students in plausible chemical problems and tasks. In combination the exercises provide opportunities for students to develop skills of information retrieval, team work, problem solving, critical thinking and communication (oral, visual and written). One exercise is described in detail. The exercises could be incorporated into any BSc Chemistry Course.

Introduction

There is widespread recognition of the need for graduate chemists to be able to communicate effectively and for undergraduate chemistry courses to ensure that these skills are developed[1,2,3]. This view is also held by employers[4]; the particular concern of the chemical industry was recently expressed succinctly by the Director of the Chemical Industries Association as follows:

"Ask employers what are the skills that freshly recruited graduate chemists most often lack, and you will get a very short list, on which interpersonal and communication skills figure large. Employers need staff who not only are good at chemistry but also can operate as part of a team, have the potential to manage others, and can communicate clearly and enthusiastically with a wide variety of people."[5]

Communication skills are a clear example of the skills which must be discovered and developed by individual students through what has been called 'experiential learning' (see for example Laurillard[6]). Experiential learning is time consuming; it involves practice, reflection on performance, and further practice in order to build on the experience. All this requires serious academic support. It is my impression that, with ever-increasing course content, and pressure to achieve high pass rates, the development of communication skills is inadequately supported at many universities.

At Heriot-Watt University in 1995, we decided to address this problem by establishing a module on *Communicating Chemistry* within the penultimate year of the chemistry degree course. Here I discuss the rationale behind the design of the module, describe one particular exercise in more detail, and present some student feedback concerning the whole module.

Rationale behind the *Communicating Chemistry* module

Why a module?

Communication skills were already a modest integral part of our existing courses. We wanted to enhance and extend th provision. There were several reasons why we chose develop a specific module on *Communicating Chemistr* Firstly, we wanted the communication skills components our courses to be more clearly identifiable and to some exte quantified. Secondly, if communication skills are learnt rath than taught, we had to earmark sufficient time for the studen to learn through first hand experience – and the only simp way of guaranteeing adequate blocks of time was by creatir an appropriate module. Thirdly, we agreed that a topic of suc importance as communication skills needed a well co ordinated educational package. Such an educational packag need not necessarily be a module, but exceptional co operation from most colleagues is required in order t produce an effective package that is fully integrated into th rest of the degree programme. There is a real risk that th learning of chemistry will take precedence over th communication skills, so that some students can avoid fu participation and so fail to realise their full potential, and als that tuition will be highly variable. A module with the them of *Communicating Chemistry* raises the status of skil development to that enjoyed by other key topics. A important reason for placing the module in the penultimat year of the course was the difficulty of creating a suitable sl in the curriculum during the earlier years.

Why a *chemistry* module?

Communication skills are largely generic, and man universities advocate centralised teaching by 'experts'. Whil this may appear to be economical, I believe it to be misguide for one simple reason; for students to really discover an develop their communication skills, the tasks they undertak must seem interesting and relevant. This point is made in th Royal Society Report which advocates that the developmer of personal transferable skills (including communicatior *"must be fully and carefully integrated into courses"*[3]. Fc chemistry students, this means using chemical situations fc developing their communication skills. There is, moreover, bonus with this approach – it is easier to convince colleague of the value of a communication skills module if it require students to discover, explain and use chemistry, rather tha *"wasting their time on wishy-washy generic exercises, whe their basic chemistry needs reinforcing"*. A good education

The Module structure

Two constraints strongly influenced the design of the module. Firstly, a single module is expected to involve 100 hours of work over an 8 week period for each student; secondly, the number of students in the cohort is about 50. We identified the following aspects of communication skills that we wished to address within these constraints:

- information retrieval;
- written delivery;
- visual delivery;
- oral delivery;
- team work;
- problem solving.

We then developed 10 exercises, most of which were designed to address two or more of these skills and which, taken together, would achieve a fairly balanced coverage. Each exercise was designed so that it could be run by a single tutor working with the whole cohort of students. However, for several exercises, the involvement of two or more tutors is hugely beneficial. Concerning the nature of written, visual and oral delivery, the exercises involve concise reports or articles (surely the most important yet under-developed written skill for many graduates), poster presentations, and short talks. In several exercises, the students work in groups or 'companies'. These are established at the beginning of the first exercise (see below). The content of the exercises is summarised in table 1.

Exercise 1, the Fluorofen Project is used as an ice breaker and it establishes the companies which will work together in exercises 2, 7, 9 and 10. It is self-contained and, with tight control, can be completed within one hour, though it could easily be extended. I describe it in some detail because it illustrates the approach adopted, and the typical interactive nature of the timetabled sessions. Further information on the other exercises is available[7].

The Fluorofen Project

The objective of this exercise is to provide the students with opportunities to develop the skills of collaborative team work, problem solving, and critical thinking. The latter two terms are defined in many ways; here they are used to describe the kind of thinking necessary to tackle the kind of problems regularly faced by professional chemists and which require judgements (see also refs 2 and 4). Although the exercise is appropriate for the penultimate year for chemistry BSc (hons) students, related team exercises pitched at this level have been

Table 1: Summary of exercises in the 'Communicating Chemistry' module

Ex. No	Title	Description	Time (h) *	Info. retrieval %	Written delivery %	Visual delivery %	Oral delivery %	Team work %	Prob. solving %
1	The Fluorofen Project	Exercise to solve a chemical problem (teams)	1 (1)	0	0	0	0	50	50
2	Scientific paper (ref 8,9)	Exercise to dissect a chemical paper (teams)	3 (3)	20	0	0	0	30	50
3	Keyboard skills	Basic skills with Word and ChemDraw (individuals)	10 (1)	0	10	90	0	0	0
4	New Scientist article	A short paper is turned into a NS article (pairs)	18 (1)	20	40	30	0	10	0
5	WWW treasure hunt	Introduction to the Net, BIDS, and email (individuals)	8 (3)	90	5	0	0	0	5
6	Dictionary of chemistry	Write brief entry for Dictionary of Interesting Chemistry (include. lit. search) (pairs)	20 (1)	35	35	20	0	10	0
7	Research poster	Produce poster on a new area of research based on NS article (teams)	12 (1)	20	25	40	0	15	0
8	Annual review talk	5 minute talk to 10-12 peers on any interesting chemistry, as part of their company's annual review (individuals)	12 (3)	10	0	20	70	0	0
9	Interview	All are interviewed by another company (CV required), AND carry out interviews for their company (individual and teams)	8 (3)	0	25	0	55	20	0
10	Hwuche-Hwuche bark (ref 10)	Business game with real chemical problems, leading to oral presentation (teams)	8 (4)	5	0	10	15	45	25
	Total		100	20%	14%	21%	14%	18%	13%

*Figures in brackets show the amount of time spent in class with a tutor present; the rest of the hours are untimetabled independent

Figure 1: Timetable for the Fluorofen Project

- 3 minutes: introduction
- 2 minutes: organise groups
- distribute *Hand-out 1* (see Figure 2)
- 15 minutes: group discussions 1
- 10 minutes: plenary session 1
- distribute *Hand-out 2* (see Figure 3)
- 20 minutes: group discussions 2
- 5 minutes: plenary session 2 and conclusion

Total 55 mins.

modified slightly to make them suitable for first year general science students, or for final year honours chemists. The timetable for the exercise is shown in figure 1 and Tutors' Notes for the Fluorofen Project are presented below.

Tutor's notes on the Fluorofen Project

Preparation by the students

Recommendation – do not require any preparation by them! This has two advantages; there need be no (dubious!) assumptions about the students having carried out background reading, and the exercise has immediate interest and impact value when started.

Introduction and division into groups

The key feature of the Introduction is that it should engage the students' attention; individual tutors will choose an approach with which they feel comfortable. This may vary from simply arranging the students in groups and providing them with the information on handout 1 to (my preference) addressing the whole class in a role play. A possible introductory presentation runs something like this:

*'Thank you for coming to this important and urgent meeting. As you know, our parent company A.C.E. has several chemistry subsidiaries; my name is ***, and I'm Head of 'PharmAce', the Medicinal Chemistry subsidiary. You may wonder why I've asked you, a top R&D team from the Agrochemicals subsidiary, to a meeting this afternoon. It concerns a pharmaceutical that is shortly to come off patent, and so our competitors will be able to manufacture and sell it too. We have well substantiated evidence that Zenaxo will be selling the drug at 30% less than our current selling price, soon after the patent ends in 6-months time. We cannot afford to lose our customer base, and we will match their price for a few months at zero profit, whilst we try to discover how we can cut our costs. As this is a large scale production pharmaceutical, your R&D expertise at scale up is invaluable ... and we also feel that a fresh look at the problem, and your proven track record at solving difficult chemistry problems, may help you come up with possible solutions by the end of this brainstorming session. Here is some more information about the drug (one can use a simplified OHP version of* handout 1; *don't distribute the handout yet, or they will read it instead of listening to you).*

The drug is called 'Fluorofen'[11], *and it has anti-inflammatory and analgesic properties. It turns out that it is excellent for treating period pains, and this has ensured a large, sustainable market worth about £50M p.a. in sales. The structure of* 'Fluorofen' *is shown this overhead, and you can see the synthetic sequence that we to manufacture it. I have only provided the bare essentials of synthesis, so that you can perhaps focus more easily on likely reas for Zenaxo undercutting us – once you've come up with so possible avenues to explore, I will provide additional informati I would like your R&D group to identify 5 or 6 possible reas why Zenaxo are able to quote such a low price for* 'Fluorofen *will collate these ideas in 15 minutes.'*

The key to the division into groups is that it should be dc quickly (see figure 1). This is difficult if students are allow to form their own groups, and the recommendation is tl they be allocated more or less at random to pre-defin groups. We refer to them as subsidiaries of ACE, and th are encouraged to invent a company name. Once they ha reorganised themselves into their groups, and have receiv *handout* 1 (see figure 2), it is important that they identify spokesperson, and that they start to write down ideas – wa them that you will ask each group for suggestions when t 15 minutes are up. If one group is stuck or slow, guide the to some of the suggestions below.

Plenary session 1

Pool suggestions on the board or OHP, picking on vario groups for one suggestion each. Some of the suggestions v have obtained are given in table 2.

Figure 2: The Fluorofen Problem (part 1)

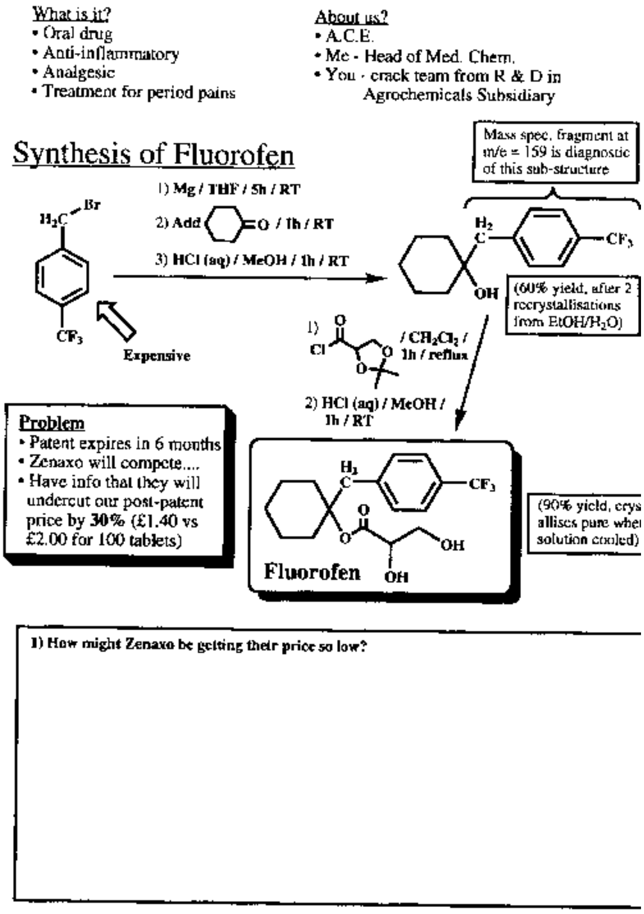


Table 2: Some suggestions for cutting the cost of '*Fluorofen*'

General ideas	Specific ideas
Lower non-chemistry production costs	Cheaper starting materials Less on packaging/marketing
Lower production costs (chemistry)	Better reaction conditions: • Temperature • Pressure • Solvent • Reaction time • Cheaper reagents (e.g. catalyst) More efficient purification Recycling: • Reactants • Solvents • By-products Improved yield(s)
Cheaper route	Completely new route Alternative key step Cheaper analogue of '*Fluorofen*'
Cheat	Zenaxo selling '*Fluorofen*' at a loss while they corner the market!

Accept all ideas; some (e.g. making an analogue) are not practicable, but nevertheless can lead to useful (brief) general discussions. At the end of the plenary session, summarise the results of the brainstorming session as follows (verbally, or on an additional handout):

'From your suggestions, it seems that the mostly likely source of cost-cutting is by improving the efficiency of the Grignard reaction. In particular, you identified:

- *High cost of starting material (but note that it probably cannot be bought or made more cheaply)*
- *Poor yield*
- *High running costs (long reaction time and high purification costs)*

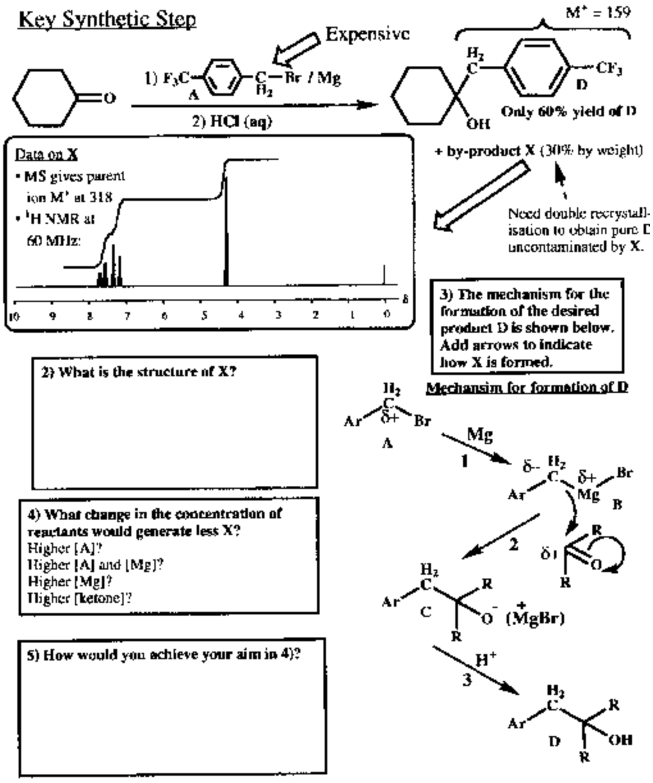
If the reaction took place more quickly and cleanly, then the cost should be reduced. (If time, ask for suggestions about how to achieve this). Rather than changing conditions by trial and error, you could try to identify impurities; this might allow you to see where the mechanism is being diverted, and then design *conditions that would reduce the formation of the by-product(s). (One can use a simplified OHP version of* handout 2 *at this stage). As it happens, we already have some information on the major by-product, and this data, together with guidance for the next brainstorming session, are provided on* handout 2.'

Then distribute *Handout 2* (figure 3), and ask them to work through points 2-5.

Group discussions 2

They should need little tutor input by now. Note that a little common sense (and minimal chemistry) will identify the by-product as a dimer of the CF_3-C_6H_4-CH_2 sub-structure, and its formation is also quite obvious (figure 4). The tutor need only guide those groups that are starting to lag behind a bit, and it works well during the Group Discussions to ask one company to put up the structure for X on the board/OHP

Figure 3: The Fluorofen Problem (part 2)



One solution: there are lots of ways that Zenaxo may be undercutting us - we would probably want to have a team *optimising* conditions (perhaps done imperfectly 10 years ago), to economise on solvents, reactants, running costs (time, heat), waste disposal. But you have identified a key problem which John Brown's group in Oxford had to solve because of another Grignard reaction they were studying; they went back to the literature to find clues to a solution (ref. 1), and carried out a careful study that provide a general procedure (ref. 2). This should work well for the Fluorofen problem, don't you think?

Refs. 1) A. Mendel, *J. Organomet. Chem.*, 1966, 6, 97.
2) K.V. Baker *et al*, *J. Org. Chem.*, 1991, 56, 698.

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Pat Bailey, HWU (18/4/9

company to suggest the mechanism for its formation (perhap adding arrows to your overhead). At least one group need to have an idea close to the answer for Q5 before the fina plenary session.

Plenary session 2

This really ought to be run as an interactive session. The ke points to cover are:

- the structure of X;
- the mechanism for the formation of X;
- that less by-product X should be formed if the [Mg] i increased;
- high [Mg] effectively means high surface area, an (amazingly) stirring dry magnesium under an iner atmosphere achieves this simply and cheaply.

Here is a possible summary, which could be presente interactively, or as a verbal statement, or in the form of memo from the parent company:

'You have come to the conclusion that the structure of th impurity is X, and that it has been formed by the followin mechanism (see OHP or board or handout). If the [Mg] could b increased, then the formation of the Grignard would be quicke and there would be less time for the dimer by-product to form befor

Table 3: Summary of student feedback for the components of the module (average feedback from 42 responses).

Responses were requested on a five-point +2 to -2 scale as follows: a) self-assessment of ability before the module (+2 = very confide +1 = confident, 0 = some confidence, -1 = little confidence -2 = no confidence); b) retrospective assessment of the value of the comp nents of the module (+2 = essential, +1 = useful, 0 = no preference, -1 = not very helpful, -2 = useless); c) retrospective self-assessme of impact of the module (+2 = big improvement, +1 = useful improvement, 0 = about the same, -1 = worse.

	a) Confidence	b) Value	c) Improvement
Write a report on a word processor	0.9	0.8	0.8
Insert images from a chemistry drawing package into this report	0.3	1.1	1.1
Give an oral presentation on a familiar area of chemistry to the class	-0.2	1.7	1.2
Produce a CV which would lead to an interview	0.6	1.4	0.6
Solve an industrial problem with degree level chemistry knowledge	-0.2	1.0	0.9
Use the internet to find information	0.7	1.0	0.8
Describe a chemical concept to a non-chemist	0.5	1.1	1.2
Research an unfamiliar topic using chemical journals	0.0	1.3	1.4
Use a database to find a piece of chemistry research	0.0	1.3	1.3
Interpret a chemistry research paper	-0.3	1.2	1.1
Produce a scientific poster	0.2	0.8	0.9

effective when they are built around a chemical scenario, and involve plausible chemical problems and tasks. It is my view that, if possible, many of the basic skills associated with effective (chemical) communication should be introduced early in a degree course – a view also expressed by many of our students. Moreover, I would advocate ensuring that a wide range of communication skills are covered – there were no areas in which all of our students were confident , and many were surprised by their improvement at aspects in which they had thought they were already strong.

Our *Communicating Chemistry* module provides one way of giving reasonable opportunities to students to develop a range of communication skills in an integrated educational package, using realistic chemical tasks that the students generally enjoy. The primary aim of the module is not to produce brilliant communicators, but to show each student where his/her strengths lie, and to enable them to improve their communication skills during the module and subsequently. Moreover, I believe that we should be encouraging our new graduates to be enthusiastic not only about their chemistry, but also about communicating their chemistry to others.

Acknowledgements

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References

1. *Report of the degree courses review group* 1992 (Royal Society of Chemistry) section 5.2
2. *Teaching and learning in an expanding higher education system* 1992 (Committee of Scottish University Principals) Appendix A
3. *Higher education futures* 1993 (The Royal Society, London) section 3.4
4. *A wider spectrum of opportunities* 1995 (Council for Industry and Higher Education) sections 3.11 and 3.20
5. Finer F. 1996 *Chem. in Brit.* October
6. Laurillard D 1993 *Rethinking university teaching* (Routledge)

7(i) Much of the material for this unit is available on disk, as hard copy, or through the Heriot-Watt WWW (URL required) – contact Pat Bailey on p.d.bailey@hw.ac.uk or 0131-451-3100.

7(ii) The RSC are supporting the development of a *Communicating Chemistry Teaching Package*, to be availab from early 1998; this will include several exercises on developing communication skills in a chemical context, with tutor's notes for running the exercises in various formats, an guidance for modifying the content. More information will be available towards the end of 1997.

7(iii) The RSC is also supporting the production of a booklet o *Communicating Chemistry*, which will be provided free of charge to all final year undergraduates in 1998.

8. Bailey P and Kerr W 1993 *Proceedings, Variety in Chemistr Teaching 1993* (ed. M Aitken) (Royal Society of Chemistry)
9. Garratt CJ and Overton T 1996 *Educ. Chem.* 33 137-138
10. Bailey P 1996 *Proceedings, Variety in chemistry teaching 1996* (eds. CJ Garratt and T Overton) (Royal Society of Chemistry)
11. To the best of my knowledge, the name '*Fluorofen*' has not been previously used, the compound so named here has not been synthesised, and there is no reason for supposing that it has the properties ascribed to it.