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Spreading the Word (about Chemical Engineering)

by

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Abstract: The current situation regarding falling undergraduate admissions to Chemical Engineering Departments in the UK is analysed with reference to the structure of secondary education. A collaboration is proposed between Departments of Chemical Engineering, local schools and industry for introducing the concepts of Chemical Engineering to school-aged children. The scheme proposed, integrates a design exercise within the teaching of organic chemistry and is aimed at increasing awareness of the discipline and ultimately, increasing the number of admissions to university departments. The proposal is intended for widespread application both within the UK and elsewhere.

There is concern in the UK academic community over the decline in university applicants to chemical engineering (Table 1).

It is an almost instinctive reaction to attempt to account for a trend as clear as that shown above, but recalling Sherlock Holmes' stern injunction that to theorize in the absence of data was a 'capital mistake', we shall refrain. Quite what would constitute hard data in this case is difficult to conceive. One is dealing with opinions and views formed over long periods of time and

subject to a host of influences. Even when a clear question can be formulated such as, why do females account for only approximately 25 % of applicants? it rapidly becomes apparent that there are no simple answers. Fretting over the causes of the decline will in any case not result in any useful outcome. Our principal concern here is with describing a proposal for halting and perhaps even reversing it. This is no easy task, and in order to make a real impact on the situation, will require implementation on a large scale.

Our basic premise is that opportunities exist within the teaching of chemistry at schools to introduce information about disciplines allied to chemistry i.e. chemical engineering. We describe below a scheme intended for integration with the teaching of practical organic chemistry. Writing in the UK we felt it logical to set out our proposal in the context of secondary school (i.e. pre-University) education in the UK. Doing this we hoped would help the non-UK reader compare and contrast the situation existing in his or her own country. In addition, it should enable the reader to better determine the most appropriate age at which the proposed project might be applied in his or her own country. This last point is very important; we are firmly of the belief that the project work we describe and equally importantly its implementation should be of universal applicability. One of us (KH) has recently returned from conducting, with other representatives of UK chemical engineering, a survey * of academic research at the top US departments. The opportunities presented to discuss other, related matters – including student recruitment - proved too great to resist. The impression gained from such informal discussions was that the US faced a broadly similar situation.

We also felt that there was scope for some industrial input and we take the opportunity to develop our ideas on this here.

But before embarking on a description, we offer a brief explanation of the process of entry to a UK University. The current matriculation route to UK (but excluding Scottish) universities is via the Advanced Level of the General Certificate of Education, commonly referred to as 'A' levels. At 16 years of age prospective 'A' level candidates at school or college will have elected to sit examinations in, typically, three subjects, which they undertake to study for a period of two years. An offer of a university place is made to individual students in the form of a cumulated 'A' level score, which may or may not, be accompanied by other constraints such as minimum grades in one or more subjects. The Scottish system is different in that students there sit the Higher Grade of the Scottish Certificate of Education ('Highers'). Students take a broader range of subjects somewhat at the expense of depth of coverage with the consequence that courses at Scottish Universities are generally correspondingly longer than those elsewhere in the UK.

'A' levels have long been criticized as requiring young people to specialize at far too early an age. This is particularly the case when compared to the majority of other European states. There is now a real prospect of change being introduced with the aim of maintaining educational breadth beyond the age of 16 without compromising depth. Whether this is achievable remains to be seen but is in any case outside the scope of this paper. Returning to the current situation, the preferred combination of A levels for entry into the majority of chemical engineering departments is Mathematics, Physics and Chemistry. The numbers of students in total taking these particular A levels has remained relatively steady over the last five years (Table 2).

However, the crucially important figures are the numbers of students presenting the combination Mathematics, Physics and Chemistry, these are shown in Table 3. The encouraging feature of this data is that it shows an increase in students offering this combination of 'A' levels. Less

encouragingly, they also reveal that the decline in chemical engineering applications has been occurring against the background of an increasing pool of suitably qualified potential recruits.

Having defined the nature of the challenge we face, this is perhaps an appropriate place to reiterate our aims. Simply put, these are to raise awareness of our discipline amongst young people. There are, undoubtedly, many ways of achieving this, but whatever approach is taken, we feel that there are certain principles that have to be upheld. The task must be seen as one of *informing* young people, it should not be seen as one of attempting to entice them away from other disciplines. It has been our experience that one gains the respect of audiences of young people if one states, and adheres to, this principle.

We do not wish to be seen as claiming that the situation which we describe here has previously gone unrecognized. Both professional and industry bodies have expended time and money in producing educational materials in a variety of formats. This has included leaflets, posters, videos and CD-ROMs aimed at exciting interest in chemical engineering in the minds of young people at school. Quite whether the producers of such materials realize what fierce competition exists for those young minds (we suspect not!) is another matter.

Those most immediately affected by falling admissions, i.e. the Universities, have responded to the situation by offering short residential courses aimed at giving young people a 'hands on' experience of different branches of engineering. Most of these schemes are aimed at 16 year olds i.e. those about to embark on their 'A' levels. The majority of these students will have made up their minds as to whether they will choose predominantly Arts or Science 'A' levels. This latter group constitutes the one that engineering departments seek to recruit students from. Whilst admirable in achieving their rather limited purposes, such schemes can really only serve to attract students away from the pure sciences or to redistribute students among the various engineering

disciplines. This is not intended as a cynical criticism of these so-called ‘taster courses’, as in many cases they have helped individuals form opinions about their careers. Nor do we argue that these courses should no longer be offered. However, it is evident that from a recruitment point of view they can have only limited impact. Numbers of applicants to chemical engineering continue to drop despite the existence of such courses. It should be equally clear that the time to promulgate the message about the virtues of a career in engineering is before age 16. At 14 years of age, for instance, fewer children will have strongly held ideas as to future careers. Most importantly they will not have committed themselves to one or other branch of intellectual endeavor (i.e. Arts or Sciences) as the British system requires. Those who have organized engineering taster courses will appreciate the resources, not least time, that must be expended to operate them successfully. In so far as engineering is about making things happen, about *doing*, it is difficult to convey the sense of achievement this produces in leaflets or videos. Herein lies our first difficulty: it is relatively simple for a university department to produce 20,000 leaflets extolling the virtues of chemical engineering, but quite a different thing to actually enable 20,000 individuals to experience chemical engineering at first hand. No single Department could hope to bring about significant changes on its own, instead, a concerted effort is required. In one sense approaches to younger children should help to eliminate some of the rivalry that exists between departments; recruitment by universities of students who attend their existing taster courses aimed at 16 year olds is not insignificant. At 14, it could be argued that the objective becomes more one of gaining a convert to science and engineering as a whole and it is unlikely that an individual would commit him or herself to any one particular department. We believe that the proposal described below could form the basis of an initiative aimed at increasing the awareness of engineering.

We decided to operate our scheme with children from a local school aged 14 years. We felt that this age group should have both a sufficient knowledge of chemistry for the project and be able to tackle what would be some quite novel concepts. Both their own teachers and we ourselves could see merits in the scheme starting in an environment familiar to them, namely their own school laboratories. The proximity of the school to the university also meant that the children could continue to make use of school resources i.e. libraries, internet access etc. The involvement of a local school had other benefits, in particular, it was unnecessary to arrange accommodation and catering. The involvement in teachers from the school was a key factor in the success and smooth-running of the scheme. The teachers had been invited to the University about a week before the scheme was implemented and were fully briefed on logistical, safety and other matters. They were given a brief overview of our laboratories (because we intended that the schoolchildren should make use of them, see below). Overall supervisory and other duties were shared between two members of academic staff of the Department.

The students were asked to undertake the laboratory synthesis of methyl salicylate. The instructions issued them are shown in Figure 1. We found it convenient to split the students up into groups of 3 or 4, each group being issued with one set of the apparatus necessary. The exercise proved to be well within their capabilities and was readily executed by the students over a 2 day period (see below). The next stage of the exercise was for the students to design a facility for producing 300 tonnes per annum of methyl salicylate. This task was performed at the University. Before starting this stage of the program, the students were reminded of the operations which they had conducted and which they would have to 'translate' to the large scale. We achieved this by mimicking the operations using water in the place of methanol and sulphuric acid and sugar in the place of the salicylic acid to an audience of students. Devoid of the

chemistry, they were able to concentrate on the actual process of introducing the reactants into a vessel, heating, mixing, cooling, etc. Although simple in concept, it proved highly effective. The design brief given to them is shown in Figure 2. We have found it preferable to divide the students into teams of not more than six. Groups of this size helped to break down the reserve felt by some individuals and lead to lively discussion without becoming unmanageable. It is essential to let the students generate ideas themselves, but it is equally important to have someone on hand to help them eliminate ideas that are evidently impractical and also to keep them on track generally. We have both personally carried out this role and have also made use of postgraduate demonstrators. Naturally these have been carefully primed for the role, emphasizing the need to gently guide the students towards a solution.

The exercise can, to quite a large extent, be tailored to fit time constraints. We have operated it comfortably over a period of five days; 2 days in the chemistry laboratory and 3 days at the university as the timetable shows (Table 4). In order to maintain high levels of enthusiasm among the students, we found it useful to intersperse this period of time with occasional forays into our teaching laboratories. In the laboratories, they were first shown, and then allowed to operate, pumps, pneumatic solids conveying equipment, valves, heat exchangers and other process plant equipment. Naturally, this was done under very closely supervised conditions.

We feel it is essential that the students obtain an overall process flowsheet relatively early on in the exercise. However, it is also important to illustrate to the students something of the depth of reasoning and the rigour that is required in the design of individual items of chemical plant. We have tended to focus on the reactor as it is central to the process and therefore consideration of what happens both up and downstream of it needs to be taken into account.

Rather than overburdening the students with large collections of data sheets and the like, we have found it preferable to provide them with information as the need for it arose. Some of the information required was specifically not made available in this manner. For example, the students were required to make use of the library to determine what materials were suitable for fabricating the reactor. Another task, that of finding the bulk selling price of methyl salicylate, required them to make use of the internet. An advantage of this approach is that it does not appear to the students as being over-prescriptive: as long as progress towards the final presentation is made there is scope for exploring at least some 'alleys and byways'.

It is perhaps not surprising in the current generation of young people to find the extent to which concern for the environment crept in to a design exercise such as this. This actually presents an opportunity, which if seized can help the participants to form a more balanced view about the chemical industry. It has been our experience that opinions held by most of the students on this subject tend to be negative ones. Such views may not be well-informed, but they nevertheless represent those which have to be confronted. The students themselves raised environmental concerns and were encouraged to see that solutions were available to meet those concerns. Importantly, they discovered this for themselves. We found that they acquired a rather proprietorial attitude, this was *their* plant, they were going to operate it in such a way as to cause minimum impact on the environment. Interestingly, no student has ever questioned the need for the plant; they seemed to recognise that such pharmaceutical products are of general benefit to humanity.

We had earlier stated that the collaboration of industry was helpful in operating a scheme such as we are proposing here. We would argue that this needs to be done with sensitivity. We have often had cause to be surprised by how alert young people are to what they consider to be overt

forms of company propaganda. We wanted to ensure that the students associated the whole exercise, primarily as a collaboration between their school and the university. We wanted to ensure that industrial involvement was altogether less obtrusive but nonetheless significant to the success of the scheme. In our case this took the form of a link with a local pharmaceutical company who undertook to conduct chemical analyses of the reaction products which the students had synthesised in their school laboratories. The students were invited to the company laboratories and given a brief tour. They were then given a brief survey of potentially suitable analytical techniques and then a fuller explanation of the one (High Pressure Liquid Chromatography, HPLC) actually used for their samples. In order to make the design exercise as realistic as possible, a number of our industrial contacts agreed to receive telephone enquiries from the students concerning the costs of shift labour. There are a number of forms which industrial involvement could take and those cited above represent typical examples only. The students final task was to make a short presentation to an audience which included their peers. This itself was a new experience for many of them and it provided an opportunity to explain their processes and present their principal findings.

We decided to prepare a process flowsheet (Figure 3) to enable the students to see what one looked like and also to allow them to compare their designs to it. We wished also to introduce the concept that in engineering it may be possible to generate more than one perfectly acceptable solution to the same problem.

We have operated the exercise described above on two successive years, in each case to groups of about 20 students. Feedback from both the students and their teachers has been extremely encouraging. It is justifiable to ask how the success of this scheme is to be assessed. It is still too early to say whether the initial enthusiasm expressed by the students will translate itself into

more of them selecting the ‘right combination’ of ‘A’ levels and ultimately electing to study chemical engineering, or indeed chemistry, at university. We view the operation of our scheme very much as a pilot exercise. In any event, we are dealing with the statistics of small numbers, and as we have already stated real benefits will only become apparent if the scheme is carried out on a significantly larger scale. The fact remains, that all those who were involved in the scheme were unanimous in finding it a useful and enjoyable exercise. If it served no other purpose than to put the chemistry which these children receive at school into a context that is not normally available to them, then we have performed a useful service.

Acknowledgement

We wish to acknowledge the work of our colleague, Dr Robin Wilcockson in devising the design exercise which we adapted as part of our initiative.

Table 1. Applications to Chemical Engineering Degree Courses in the UK*

| Year | Male | Female | Total |
|-------------|-------------|---------------|--------------|
| 1994 | 1017 | 324 | 1341 |
| 1995 | 913 | 353 | 1266 |
| 1996 | 897 | 328 | 1225 |
| 1997 | 873 | 319 | 1192 |
| 1998 | 787 | 324 | 1111 |

Table 2. Numbers of Students Sitting ‘A’ Level Examinations by Subject (Source: Qualifications and Curriculum Authority, London, 1999)

*The figures shown here were derived from data supplied by the Universities and Colleges Admissions Service {UCAS} based in Gloucester. Under existing conditions, students may apply for entry to up to six university departments in any academic discipline (prior to 1996, this number was eight). The vast majority of students apply to

| Year | Mathematics | Physics | Chemistry |
|-------------|--------------------|----------------|------------------|
| 1994 | 67,984 | 36,600 | 41,805 |
| 1995 | 65,892 | 35,234 | 42,836 |
| 1996 | 68,709 | 33,361 | 40,917 |
| 1997 | 70,414 | 33,657 | 42,841 |
| 1998 | 71,615 | 34,518 | 43,385 |

Table 3. Numbers of Students Sitting ‘A’ Level Examinations in the Subject Combination Mathematics, Physics and Chemistry. (Source: Qualifications and Curriculum Authority, London, 1999)

| Year | Number of Students |
|-------------|---------------------------|
| 1994 | 8,507 |
| 1995 | 8,762 |
| 1996 | 8,069 |
| 1997 | 8,794 |
| 1998 | 9,754 |

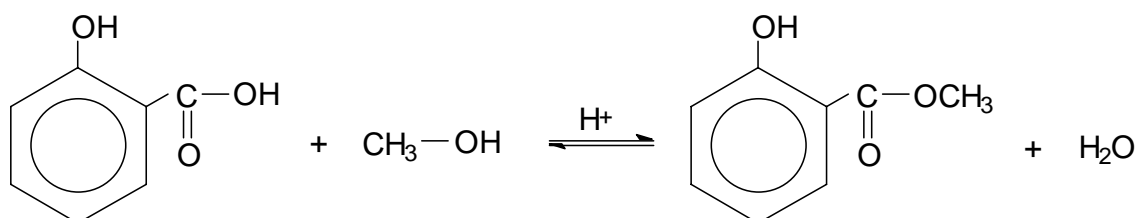
Table 4. Programme Timetable

| Monday | Tuesday | Wednesday | Thursday | Friday |
|--------------------------------------|---|--|--------------------------------|----------------------|
| Introduction to the Programme | Laboratory Synthesis | Introduction to the Strategy of Design | Group A Labs Group B Design | Design (both Groups) |
| Introduction to Chemical Engineering | | Group A Labs Group B Design | | |
| Lunch | Lunch | Lunch | Lunch | Lunch |
| The Chemistry of Salicylates | Visit to Industrial Analytical Laboratory | Group A Design Group B Labs | Group A Design Group B Labs | Design Presentations |

the maximum number of departments to study a single discipline. We have assumed this to be the case in arriving at the figures presented above.

You are to carry out the synthesis of methyl salicylate. This is one of the active ingredients in the traditional remedy known as 'Oil of Wintergreen.' Methyl salicylate has a pattern of action similar to that of aspirin i.e. cure for headaches and other general low level aches and pains. Take 1 mol of salicylic acid (2-hydroxybenzoic acid) and react with 5 mol of methanol using 0.2 mol concentrated sulfuric acid as catalyst. The reaction should be carried out under reflux conditions (boiling of the mixture) for 5 hours. Extract the product into an equal amount of cyclohexane. Wash the organic phase with aqueous sodium carbonate solution and dry subsequently over anhydrous sodium sulfate. Distill to remove the cyclohexane and analyze your product.

The reaction scheme is given below:



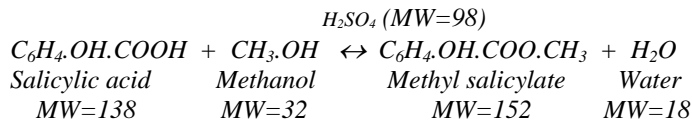
What does the sulfuric acid do ? Why do you use excess methanol ? Why do you wash with sodium carbonate solution ?

You will have to assemble your own apparatus from the glassware provided.

This is a simple and safe synthesis to carry out provided that you adhere to normal safety procedures.

Figure 1. Instructions for the Laboratory Synthesis of Methyl Salicylate

You are required to prepare an outline design and provide preliminary costing for an industrial facility to produce 300 tonnes per year of methyl salicylate. Methyl salicylate is produced by the reaction of salicylic acid and methanol in the presence of H_2SO_4 as follows:-



The reaction takes 5 hours at the boiling point of the mixture. The methyl salicylate product separates out as an immiscible liquid layer, which subsequently has to be washed with dilute sodium hydroxide and then with water. To be cost effective, the industrial process operates somewhat different to the laboratory scale experiment.

The facility will be operated as a batch process but you are free to choose any operating pattern you consider suitable (e.g. 8 or 24 hours per day, 5 or 7 days per week, all year round campaigns etc.). You may assume that sales demand is spread reasonably evenly over the year.

Your task:

You will be split up into design teams for the purpose of this exercise and you are expected to elect one of your team members as team leader and s/he will be responsible for co-ordinating the teams' activities and for ensuring that a design is produced in time to make a brief presentation. For this, you will be issued with only two overhead transparency sheets. You should consider the following:

- How you are going to make the reaction happen
- How the plant is to be operated
- The size and cost of your reactor (in m^3)
- How you will get the raw materials into the reactor
- How you are going to avoid environmental pollution and what opportunities exist for recovery of raw materials.
- What other considerations would have to be taken into account in determining whether your plant will operate at a profit.
- Will this process yield a saleable product ? If not, what additional steps need to be taken ?

Figure 2. Design Specification for a Plant to Produce Methyl Salicylate

Figure 3: Flow Sheet for a Methyl Salicylate Production Facility

