

Introducing Chemistry Students to the “Real World” of Chemistry

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Kerr and Runquist (1) ask the provocative question, “Are we serious about preparing chemists for the 21st century workplace or are we just teaching chemistry?” They found that (i) the desirable characteristics listed by potential industrial employers did not correspond well with the criteria used to admit students to graduate school; (ii) 75–85% of their graduates were headed for industrial careers; and (iii) few science faculty members had experience in, or contact with, industry and most were “unaware of or insensitive to the expectations and challenges of the 21st century technological workplace”. They describe their efforts, with the help of industry, to develop strategies and initiate programs to address these problems. Melton (2) reports on a symposium on Education for Industry, held by the American Chemical Society in 1996 and quotes industrial employers as being unable to afford to continue the lengthy in-house training (12–18 months) necessary for chemistry graduates to become productive in their new environment. The article lists some of the useful resources available at that time for improving the employment prospects of the 70% of chemistry graduates that enter industry. A reviewer pointed out some very general background information on entrepreneurship that is available on the Europa Web site (3).

The training of chemists in South Africa has been carried out via the traditional science degrees at universities and through various diplomas offered by technical universities (technikons). In recent years, the universities and technikons have merged and the resulting institutions have offered programs leading to bachelor's degrees in either science (BSc 3 years) or technology (BTech 4 years). Postgraduate studies can then lead to an honors degree (1 additional year), a master's degree by coursework or thesis or combination thereof (minimum of 1 additional year), and a doctorate by research thesis (unspecified time frame). The program for a BTech degree with chemistry as a major subject will usually involve some contact with the chemical industry. However, the majority of students completing a BSc degree with chemistry as a major subject will have little or no contact with this “real world of chemistry” unless they are recipients of funding from chemical companies for their studies and are expected to work in these companies during their long vacations. The majority of BSc students thus could have their first contact with chemical companies when they enter the labor market, following graduation.

Unemployment in South Africa is high, and yet, there is a shortage of skilled labor resulting from the inequalities of the former political and educational systems and the problems of correcting these educational disadvantages. Much emphasis

has been placed on the need for people to become small-scale entrepreneurs with the prospects of growing small businesses and providing employment for others. With this in mind, we introduced an entrepreneurial practical project into our second-year course in 1994, to emphasize that knowledge of chemistry can be a considerable asset in the business world. This attitude is developed further in the third year, using the thought-provoking statement made by Reuben and Burstall in their book *The Chemical Economy* (4) that “The chemical industry exists not to make chemicals but to make money.”

Second-Year Chemistry Entrepreneurial Projects

The class (20–35 students) is divided into teams of 4–5 students. The teams are arranged by the instructors after looking at the academic records of the students in their first-year of studies so that the talents are balanced. This balancing does not occur if students are allowed to form their own teams (5). Each team is assigned a product and assigned an instructor to act as a “consultant”.

The types of products that have been examined include polishes (e.g., shoe, furniture, floor, car, etc.); cleaners or polishes (e.g., silver, brass, glass, etc.); detergents (e.g., household, dishwashing, carpet shampoo, car wash-and-wax, fabric softener); adhesives (e.g., wood, paper, etc.); paints (e.g., acrylic, luminous, varnish, fungicidal, etc.); and miscellaneous (e.g., woodfiller, window putty, rust remover, paint stripper, dog repellents, insect repellents, fabric dyes and fabric paints, pottery glazes, etc.). More technologically sophisticated items, such as light sticks, breathalyzers, swimming pool test kits, water hardness test kits, air fresheners, glue sticks, and color pens have been tried, but these have generally proved to be less successful in the time frame available. Cosmetic and pharmaceutical products of any kind that involved extensive skin contact were excluded, as would other products with obvious associated hazards.

Some lectures and guidance on the financial aspects of setting up a small business enterprise were provided. Students learn how to work in teams, do market research, SWOT (strengths, weaknesses, opportunities and threats) analyses, and how to draw up balance sheets. Teams are also provided with the details of how the project would be assessed by the instructors. The written report and the oral presentation (see the supporting information) are given equal weighting. Teams are required to meet regularly, to elect a chairperson, and to keep meeting

minutes. They are also required to keep their consultant (assigned instructor) informed of their progress and to get the consultant's help in choosing a formulation and obtaining the starting materials. When an appropriate formulation or recipe for making the product had been approved, assistance was given in obtaining prices and in placing orders. A stock of likely ingredients, such as waxes, solvents, surfactants, extenders, binders, and so forth, has been accumulated to avoid delays in getting started. Teams then try out the formulation on a small scale and test the product in its proposed application. Fine-tuning of the formulation is usually necessary. Market research on the competition that their product would face in the market place has to be done by each team and the quantities to be made and the prices have to be decided taking into account the cost of the ingredients.

Although there is a large amount of information available via the Internet, various editions of *The Chemical Formulary* (6) have been consulted. One drawback of the latter source is the use of common (rather than more systematic) names for some of the ingredients, making them difficult to identify.

One of the first lessons that the students learn is that commercial products of a "chemical" nature are seldom made up of pure compounds. Even the solvents used are likely to be rather vague products of some company's distillation process, used as obtained at a "bargain" price without further purification or identification. It is this type of formulation that probably acts more effectively than patents or copyrights in protecting the product from duplication by competitors and usually makes attempts to do a full chemical analysis of a rival's product difficult. Once a trial batch of product has been prepared and has been shown by testing, preferably in comparison with commercially available products, to serve its purpose, attention can be directed at its packaging and marketing.

The two culminations of the project are the submission of a report and the product launch. The latter has been one of the great successes of the project. An afternoon is set aside and each team is allocated 25 min for their presentation and 5 min for questions. The originality and ingenuity of the teams in launching their products has made this an eagerly awaited entertainment among the instructors and postgraduate students. A future development may be to take entrepreneurship a step further by charging for seats in the lecture theater! During the presentations, instructors (who are expected to have read and assessed the submitted reports) act as judges of the product.

As part of the total assessment, each team member submits a written evaluation of his or her own contribution to the project and of the contribution of each team member. This is an important peer-based input in determining the final mark assigned to each student (see the supporting information). To add to the "real world" competitive nature of the project, we obtained sponsors of monetary prizes for the best team.

Comments from Second-Year Students

Students generally appreciated using their developing skills in chemistry to formulate and market a product. Descriptions of the project included "exciting", "valuable", and "challenging". For many, the entrepreneurial lectures were an eye-opener to the business opportunities that could lie ahead in their careers, as well as an introduction to financial statements. The students were

also exposed to the problems of waste management and the environment. The experience of working in teams was highly valued and the students commented on the motivation by the stronger members and the drag effect of the weaker members, as well as the need for effective communication between team members. Teams enjoyed the opportunity to work on their own with assistance available on request. Several students commented negatively on the time restraints and the competing pressures from other subjects.

Third-Year Chemistry Project

In their final undergraduate year, the need to consider how profits can be generated by making chemicals (4) is taken a significant step further. The third-year class (usually 15–20 students, all of whom have done the second-year project) is divided into balanced teams (as done in the second-year project) of 4–5 members. Each team is assigned a specific chemical product and studies the feasibility of establishing an industrial plant to manufacture and market this substance on a commercial scale. Choosing suitable products for manufacture was not straightforward, and after several less-successful trials, we decided to focus on *fine* chemicals (7) to be produced in *batch* processes. Some of the products that have been used for the project include ascorbic acid, citric acid, acrylonitrile, aniline, phthalic anhydride, isopropanol, maleic anhydride, saccharin, atrazine (insecticide), ibuprofen (anti-inflammatory), paracetamol (acetaminophen), hexachlorophene (antibacterial agent), hexylresorcinol (anesthetic, antiseptic, and antihelmintic), butylated hydroxyanisole (antioxidant food preservative), *N,N*-diethyl-*m*-toluamide (insect repellent DEET), oxolamine (spasmolytic), methyl red, methyl orange (indicators), lofexidine hydrochloride (antihypertensive), procaine, lidocaine, benzocaine (local anesthetics), and procainamide (antiarrhythmic).

As a variation on the themes used, one of the projects was devoted to the economics of recycling and the teams had to explore recycling of steel cans, aluminum cans, and poly(ethylene terephthalate) (PET) articles. This variation was not successful because very little chemistry was involved compared to the logistical and engineering challenges.

Teams are required to meet regularly, to elect a chief executive officer, and to assign portfolios to team members. Instructors, with their different areas of expertise, are asked to be available for consultation, as required, by all of the teams. Some lectures and tutorials are provided to introduce typical industrial unit operations, such as scaling up and the important balances of mass, energy, and finances. Grinbaum and Semiat (8) give several reasons for teaching some engineering principles to chemists. The main reason is that chemists that have no exposure to industry tend to attempt to solve industrial problems with the limited range of laboratory tools and techniques to which they have been exposed, without realizing that there are better solutions available. Providing chemists with a widened exposure enables them to communicate more effectively with engineers. The authors (8) identify several important weaknesses in the training of chemists. Among these are (i) little if any exposure to flow processes including concepts of the steady state and feedback; (ii) difficulties with mass balances, in spite of training in reaction stoichiometry; (iii) optimizing yields in complex systems; (iv) lack of emphasis on heat transfer in courses on chemical thermodynamics, leading to difficulties with energy

balances crucial to scale up; and (v) no exposure to continuous reactors. Although chemists deal with the physicochemical principles of separation processes, their experience of practical applications of distillation, extraction, and crystallization is limited. The authors recommend that a compulsory course in the principles of process engineering be given in every university chemistry department. A recent book (9) describes such a course.

Ottewill and Walsh (10) describe the use of consultancy exercises, where teams of students work together (with advice available from instructors) to solve industrial problems and, in the process, begin to learn about factors such as meeting deadlines, staying within budgets, and conforming with environmental and other legislation. These exercises ended with the teams presenting their proposed solutions to the problems assigned for discussion and comparison with the actual responses of industrial consultants. Hartman (11) discusses the optimal use of industrial plant tours. He recommends the submission of a brief "pretour report" before the visit, followed by a detailed report, answering key questions provided to the students (see Figure 1 of ref 11), after the tour.

Although financial aspects are covered in the second-year project, further input is available and guidance is given in assessing the financial feasibility of manufacturing and marketing the product. Again a report is required (with more detail than in the second-year project) and the product proposals are presented to a "board of directors", consisting of instructors from the chemistry and business departments of the university. Criteria used for assessment of the reports and presentations are supplied to the student teams and instructors at the start of the project. Team members are required to evaluate each other's contributions as previously described.

As part of the project, a visit is organized to a chemical plant so that students can see and get a feel for the scale of industrial processes (11). An alternative, with fewer safety and transport considerations, might be the use of video material. This option has not yet been explored.

Although the presentations have not had the entertainment value of the second-year product launches, they introduce both the student teams and most of the audience to the realities of the chemical industry. The balancing of the amounts of chemicals in use, the efficient use of energy, and the need to provide an attractive return on an investment of capital is an essential aspect of any "real" chemistry. Another true-to-life experience, introduced by this type of project, is the task of finding both financial and thermochemical information concerning the reactants and the products. We have tried to limit the annoyance caused to chemical suppliers by students asking for prices of specific tons of reagents that they have no intention (or means) of purchasing by using international prices published in sources such as *Chemical and Engineering News* and allowing some factor for transportation. When thermochemical data for specific compounds are not readily available, students are advised to use values for similar compounds or to use methods of estimation from molecular features (12).

The third-year project requires more chemical knowledge than the second-year project. However, because this is only a study, there is no danger that a poor estimation or a miscalculation could lead to a catastrophe! We also obtained sponsors of monetary prizes for the best team.

A further variation introduced in 2008 was to task the student teams with different manufacturing aspects of a single product. We chose biodiesel as the product and the teams drew lots for their tasks: chemistry, equipment, feedstocks, economics, or environmental aspects. The teams had to cooperate rather than compete. The project started with a visit to a local biodiesel plant. The groups had to meet regularly to report so that each group was aware of the progress made. Prizes were awarded to the member of each group who was voted by his or her colleagues as having contributed most.

Comments from Third-Year Students

Among the things that the students say that they gained from the project were experience with working in a group; presentation skills; exposure to the chemical industry, especially through the tour of the plant; the ability to think creatively; and to think of real issues that are of concern beyond chemistry in the context of the undergraduate lab. There seemed to be general agreement that the financial aspects learned during the second-year project were sufficient for the third-year project.

Conclusions

No one would scale-up on the basis of the results of these projects without the input from chemical engineers, but the exercise served to open up the interface between chemistry and chemical engineering (9). Over the years, we have tried to trim the requirements for reports to the bare essentials. Students have tended to get "carried away" with extensive mission statements, company visions, SWOT (strengths, weaknesses, opportunities and threats) analyses, and so forth. Pages have also been spent on arguing the case for location of a chemical plant in a particular region. We have thus eliminated these aspects and fixed the location. We have also limited discussion of safety aspects to those specific to the product concerned, rather than to the safety of the chemical industry as a whole! One of the major weaknesses of the reports submitted has been the lack of adequate provision for paying employees (and even the team members in their assumed portfolios) for their services! A rider to the statement by Reuben and Burstall (4) about making chemicals and making money could be that the people who make the chemicals have to be paid! Although we try to choose products for assignment that are likely to be profitable, there have been student reports that suggest the opposite for certain products. These have excellent illustrative value, especially in the light of the second-year projects, in that, other than time and paper, no major expense has been incurred in the exercise.

Notes

1. Deceased

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Supporting Information Available

Student handouts for the second-year and third-year project. This material is available via the Internet at <http://pubs.acs.org>.