ENGINEERING AND MATHEMATICS: SHAPING CURRICULUM AND CAREER MOVES

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Introduction

The community in general has a very good appreciation of many of the professions vital to today’s society. Through television and the wider media people generally know what doctors and lawyers, policemen and dentists do in their day to day activities. The same cannot be said for the engineering profession however. The popular image of the professional engineer is a man who wears a hard hat and builds bridges, tunnels and tall buildings. This inaccurate perception does not recognize the increasing number of women engineers nor the range of diverse engineering disciplines including aeronautical, chemical, civil, electrical, environmental, marine, manufacturing, naval, petroleum and software engineering.

If this is true for the general community it is certainly true for the secondary school community. Students and teachers alike usually do not have a full appreciation of the diversity of challenges and opportunities that await them in an engineering career.

While any secondary school student wishing to enter a university engineering program must have a high degree of competency in mathematics,
most secondary school mathematics teachers do not have an appreciation for the engineering discipline. Whether they are teaching simple algebra or more advanced calculus, mathematics teachers at any year level are often confronted by students with questions such as “Why are we learning this?” and “What is this used for?”

When considering possible careers, secondary school students are often heavily influenced by their teachers. A teacher with a misconception of the engineering profession could, over their own career, encourage a generation of students to choose careers other than engineering. In some cases teachers have been known to actively discourage their brighter students from studying engineering. This is often particularly true at some single-sex schools.

In order to continue attracting very good students into its courses, the Faculty of Engineering at the University of Melbourne recognized in the early 1990s that it must work more closely with the school community to raise the profile of the engineering profession among prospective students. Successful activities include the University’s annual Open Day, the Faculty’s annual one-day seminar for secondary school teachers of mathematics and science introducing them to the engineering profession, and visits by academics and undergraduate students to secondary schools.

Mathematics is the science that underpins all engineering. Good engineers must have superior mathematical skills and a sound grounding in analytical principles. Recognizing this in recent years the Faculty of Engineering has joined with the Mathematical Association of Victoria (MAV) in various activities. These include sponsoring the MAV’s Maths Talent Quest, contributing to the MAV’s Professional Development program and participating at the MAV’s Annual Conference. It also includes the exciting collaboration between the Faculty’s academics and secondary school teachers to publish a series of books. These books contain activities and information of an engineering nature that both provide material useful for the classroom as well as lifting the profile of engineering within the school community.

This paper details the collaboration between the University of Melbourne and the Mathematical Association of Victoria in increasing the awareness of the engineering profession in secondary schools as well as promoting the study and importance of mathematics in the broader community. It also describes some of the material prepared in recent years which illustrate the application of mathematics in the engineering profession.
Designing a Tank Farm

Shallcross (1995; 1996) presented a project involving the design of a bulk liquid chemical storage facility. More commonly known as tank farms these facilities may be found beside refineries and other chemical plants. They consist of large cylindrical tanks often measuring more than 10 metres in diameter and standing over 10 metres in height. Examples in Victoria include the tank farms immediately to the south and north of the western end of the Westgate Bridge in Melbourne and those next to the Shell on the northern outskirts of Geelong. Because of the hazards which would be posed to the environment by the escape of any chemical spills, the tanks are usually surrounded by an earthen wall or bund. In the event of a leak in one of the tanks the escaping liquid would be confined to the area within the bund. Government regulations as well as the Australian Standards strictly stipulate factors such as the height of the bund wall, the minimum distance between the bund and the tanks and the liquid volume that the bunds must be able to contain.

In this presentation at the 1995 Annual MAV Conference participants were shown how a basic understanding of the volumes of cylinders and rectangular prisms could be used to design the layout of a bulk liquid chemical storage facility (i.e. a tank farm) for the storage of dangerous goods. Engineering considerations and the relevant government regulations and Australian Standards were discussed. Coode Island, the facility at which a fire occurred in 1991, is used as an example that would be known to Melbourne participants and their students.

In 2000 this activity was expanded by the publication of a book, ‘Investigative Projects in Engineering: Designing a Bulk Liquid Chemical Storage Facility’ (Shallcross, D., Dell’Oro, D., Lamson, D., Schaffner, M. & Vincent, J., 2000). Co-written by Shallcross and four practicing mathematics teachers, this book is written for teachers. The first section of 25 pages presents background material on the design of tank farms which covers the basic engineering principles in language for the non-engineer. Included is information on the 1991 Coode Island fires including an explanation of what happened during the incident. The second half of the book contains teaching materials suitable for use in Years 9 to 12 mathematics subjects. Some are simple exercises of area, rates and volumes, while others cover topics including binomial distribution, probability, circular...
functions, exponential growth and decay, logarithms and calculus. Some problems are designed to be completed in 2 to 5 lessons while two 7-day projects are included. These teaching materials have been prepared by practicing mathematics teachers who understand the needs of teachers.

This book is but the first in a series of books, ‘Investigative Projects in Engineering’. The intention is to bring together engineering academics and teachers to produce informative and interesting books that demonstrate how engineers use mathematics in their daily work.

Mathematics and Environmental Engineering

The environment and recycling are subjects with significant appeal to students. O’Connor (1998) presented a project in which simple mathematics could be applied to consider the environmental and economic benefits of recycling plastic beverage containers collected from households. The plastic containers were to be recycled to generate a lower grade plastic that could be sold for use in the automotive industry. The project considered the environmental and economic costs incurred in collecting material from the curbside. In the project students and teachers would be free to vary such factors as the amount of plastic containers recycled per household per week, and the density of the dwelling in a given area. Knowing the amount of containers available for collection per street or neighbourhood, students would then be able to factor in the cost, in environmental and economic terms, of the collection of containers for recycling. The costs incurred in the actual recycling process are also discussed. At the conclusion of the presentation O’Connor worked through a case study for the teachers.

Estimating Construction Costs Using Simple Ratios

You are an engineer working for a company which is planning to build a new processing plant to manufacture ammonium phosphate. This is an important chemical used in quick dissolving fertilizers and as a fire-retarding agent for wood, paper and cloth. You have been asked to perform an economic analysis on the proposed plant to determine whether the profits made from selling the ammonium phosphate will justify the large investment required to build the plant. To do this you will need to be able to reliably estimate the cost of the major items of equipment as well as the capital cost of building the entire processing plant. Because such plants which cost tens of millions
of dollars to build are rarely built in Australia you will be forced to rely on historical cost data based upon the construction of similar plants around the world over the last few decades.

Chemical engineers regularly use this type of historical data to estimate the cost of building a similar chemical plant elsewhere in the world. Ratios are used to account for factors such as differences in the size of the plant, inflation, the difference in the construction location and currency exchange rates. The estimates are usually accurate to within ±30%. In the paper by Shallcross and Covey (1997) presented at the MAV’s 1997 Annual Conference the authors consider the example of an ammonium phosphate plant that was built in US in 1987. The plant, with an annual production rate of 254,000 tonnes, cost US$7.4 million to build. How much would it cost to build a similar plant with a manufacturing capacity of 315,000 tonnes in Australia in 1997? The authors show how using ratios enables the cost to be estimated at A$22 million.

The Mathematics of Control

For a petrochemical processing plant to operate safely and economically, all the important process variables such as temperatures, pressures, liquid levels and flow rates must be kept at their designed values. Because of the process disturbances that are inevitably present in any process plant, it is not possible to set the variables such as temperature at their designed values and then just leave them. These process variables must be continually monitored and controlled to ensure that they are maintained at their proper values, or at least within certain prescribed limits.

Up until the 1940s process plant control was achieved manually by employing large numbers of operators who opened and closed valves, or turned on or off heaters in response to fluctuations in the position of the needle of a pressure gauge, or a thermometer reading. As technology advanced and chemical processing plants became more complex, safe manual control was no longer possible. The task of controlling a process was taken up by automatic controllers. In large plants these controllers monitor thousands of process variables, adjusting flow rates, temperatures and pressures to ensure the entire process operates efficiently.

In the home we see examples of control systems in operation in the toilet cistern and the kitchen oven. A simple mechanical device is used to maintain
the correct level of water in the cistern, while in the oven an electronic controller is used to maintain temperature by adjusting the flow of gas to the burners or the amount of electricity supplied to the heating elements.

Modern control systems make use of sophisticated mathematics to ensure processes run smoothly. In a paper presented at the 1999 MAV Annual Conference and at MAVRIC 2000, Shallcross (1999) presented an explanation of the mathematics behind the simple process of heating a stream of water using a simple electric heater. Using simple Microsoft Excel spreadsheets teachers and students are able to see graphically what happens to the temperature of the water when factors such as the flow rate are changed suddenly. How long will the process take to respond to the change?

Getting Oil Out of the Ground

Petroleum is the name given to oil and natural gas found in underground reservoirs. These reservoirs do not exist as deep caverns filled with oil and gas but rather as the countless pores that exist throughout the oil-bearing formation. Over millions of years the oil, gas and also water migrate through the network of tiny pores until they come to some barrier which may be an impervious layer of rock. The oil, gas and water continue to gather in these pools until huge reservoirs of petroleum have formed.

The first oil well was drilled in Pennsylvania in August 1859. The well was just 21 metres deep. The oil flowed from the well at a rate of 25 barrels per day, what would today be considered a very low flow rate. Since then the oil industry has explored the world looking for more and more oil to drive our society. Oil is used not only to provide fuels such as petrol and gasoline, but also to provide chemical feedstock for the production of a range of important chemicals such as plastics, rubbers, coatings and paints.

Today petroleum engineers venture offshore and into the Arctic Circle to seek oil. They often drill to depths greater than two kilometres to produce the oil. Whether onshore or offshore these reservoirs often exist under great pressure so that when an oil well is drilled in to them the oil may gush to the surface. If care is not taken then blowouts will occur when the oil, gas and water will rush uncontrollably to the surface.

In a parallel paper, Shallcross (2000) describes the processes that drilling and production engineers follow to drill and complete oil wells. These wells can be kilometres deep but only centimetres wide, yet the engineers are able
to drill them with great precision, hitting the target reservoirs which are sometimes only metres wide. The author presents some mathematical challenges for the classroom that relate to data fitting and the use of contour plots.

**Making Milk with Mathematics**

Students of all ages readily relate to dairy products such as milk. Modern dairy processing plants which produce milk and other products such as cheese and whey protein concentrate require both hygienic design as well as a sound understanding of engineering processes.

Fresh, untreated cows milk contains micro-organisms that can be harmful to humans. In order to kill these micro-organisms the milk is heated to a temperature around 75°C and kept at that temperature briefly before being cooled. This process is known as pasteurisation. All dairy products including skim milk and cream must be processed in this way. In a further process known as homogenization the milk received at a dairy processing facility has the fat and protein separated from the milk and then recombined with it again in a set ratio. This helps to ensure that the ratio of protein to fat in the prepared milk is constant throughout the year even when the ratio in the milk received from the farms varies with the seasons and between different farms.

Leigh-Lancaster and Shallcross (2000) explore some of the mathematics behind the pasteurisation of cream. In heating the dairy products care must be taken to ensure that the specified temperature is obtained. If too little heat is applied to the milk or cream then the temperature will not be hot enough to kill all the micro-organisms, while if too much heat is applied the temperature will be too hot, degrading the quality of the milk or cream.

Engineers designing the equipment which heats and then cools the milk must know the amount of energy that must be applied to heat the milk or cream to the right temperature. The activity described by the authors considers how an important property of the cream, the heat capacity, varies with temperature and fat content. This material addresses the suggested theme of ‘Fitting functions to data’ and Starting Point 1, ‘Modelling data from tables’ for Victorian Certificate of Education (VCE) subject, Mathematical Methods.
Engineering Experiments using Data Logging Calculators

Some of the newer calculators on the market feature the ability to log data from probes. These probes include ones that measure temperatures, pressures, light intensity, gas concentrations and solution concentrations. At the time of writing, a project is presently underway in which a series of simple experiments are being devised that make use of the data logging capability of these calculators. These experiments will illustrate physical and mathematical principles important in engineering activities.

As an example, one experiment will make use four light sensors. A transparent column will be filled with a transparent but relatively viscous liquid. Four horizontal beams of light will be shone through the column of liquid at different levels. The beams will be aligned to pass through the column, each shining on its own sensor. The beams will be a known vertical distance apart. A ball will then be dropped to fall through the column of viscous fluid, cutting the beams of light as it passes through them. The times at which the beams are cut will be recorded by the data logging calculator. By conducting the experiments several times under slightly different conditions the students will be able to apply simple mathematical equations to the data to determine the viscosity of the viscous fluid.

It is hoped that a series of low cost and safe experiments will be devised that may be used in the classroom that have definite engineering applications.

Concluding Remarks

Much can be gained by the collaboration of engineering academics and mathematics teachers. By jointly preparing material covering diverse topics such as those outlined above, teachers will gain a valuable teaching resource while at the same time the profile of the engineering profession will be enhanced in the secondary school community. Teachers and students alike will gain a better understanding of the profession while at the same time the academics will be able to give their full support and encouragement to the exciting study of mathematics.

The inaccurate stereotype of engineers and engineering as being dull, unimaginative and male-dominated must be broken and students must be provided with at least a hint of the diverse, challenging and exciting careers
that await them in the international profession of engineering through the successful study of mathematics.

**References**


