Engineering Management Skills: the present and the future for Technical Graduates

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Norman Fortenberry, director of the U.S. National Academy of Engineering’s Center for the Advancement of Scholarship on Engineering Education, said that the move toward interdisciplinary engineering curricula is definitely a trend. “It is in response to an increasing consensus within the engineering education community,” he said, “but more importantly in the employer community.” [1]

In reviewing the Personal Skills in Chemical Engineering Graduates, B R Dickson and C D Grant from the University of Strathclyde, Department of Chemical and Process Engineering, Glasgow, Scotland- suggest that the development of skills within degree programmes can meet the needs of employers, yet there is still further work to be done that a relevant post graduate qualification could provide.

In this paper, transferable’ (or ‘personal’) skills are defined as the five key skills of: communications; team-working; problem solving; numeracy and IT skills; self-learning. It shows, with some specific examples, that there are ample and varied opportunities to develop these skills within most engineering programmes. The paper then attempts to identify whether the skills possessed by new chemical engineering graduates match the requirements of employers, using two recent comprehensive surveys, including a major survey of chemical engineering graduates with a few years in employment. The paper concludes with some views for further “on the job” training options that could be made available to the technical mangers of the future.
1.0 Introduction

There is an increasing demand from employers that graduates should have a range of transferable skills in addition to their subject-specific knowledge and understanding and Norman Fortenbury’s view

In the first part of this paper, transferable skills are defined and prioritised, and the ways in which they can be developed within the chemical engineering curriculum are considered. There is an attempt to assess the extent to which the skills acquired during education are adequate for the requirements of professional employment, using published views of employers and the graduates themselves. Finally, there are some suggestions about the implications for the future of chemical engineering education. This analysis is mainly for post graduate level and considers what skill sets may still be lacking.

1.1 Transferable Skills – Definitions and Relative Importance

The outcomes of any educational programme can be expressed in terms of two main aspects: ‘knowledge’; and ‘skills’. Skills can be divided into those that are specific to the type of programme (for example for chemical engineers, ‘skills in solving material and energy balances’, and those that are ‘generic’ or ‘transferable’ (for example ‘problem-solving skills’). In the context of higher education, there is also frequent reference to ‘graduate skills’, but these generally mean the same as transferable skills at the level expected of a graduate. This paper is concerned mainly with transferable skills.

Many statements of transferable skills can be found in the literature. There is however considerable agreement with the main skills and some illustrative statements, from a range of sources, are summarised in Table 1. It should be noted that there is little difference between the transferable skills that are expected of a chemical engineering graduate (1,2) and the skills expected of graduates in general (3,4,5) and it would be surprising if there were significant differences. On this basis, and for the purposes of this paper, the five key transferable skills are defined in Table 2.
### Table 1: Definitions of Transferable Skills [2]

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<tbody>
<tr>
<td>Teamwork</td>
<td>Communications</td>
<td>Motivation</td>
<td>Communicate</td>
<td>Communicate</td>
</tr>
<tr>
<td>Solve problems</td>
<td>Teamwork</td>
<td>Numeracy</td>
<td>Numeraite &amp; IT Literate</td>
<td></td>
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<tr>
<td>Communicate</td>
<td>Time Management</td>
<td>Communication</td>
<td>Inter-personal relationships</td>
<td>Initiative</td>
</tr>
<tr>
<td>Lifelong learning</td>
<td>Inter-personal</td>
<td>Solve problems</td>
<td>Embrace change</td>
<td>Teamworking</td>
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<tr>
<td></td>
<td>Lifelong learning</td>
<td>Lifelong learning</td>
<td>Lifelong learning</td>
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<td></td>
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<td></td>
<td>Flexibility</td>
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</table>

### Source

1. ABET 2004 General criteria for accreditation of all engineering programs (USA) [3]
3. AGR 2004 Association of Graduate Recruiters (UK) – all graduates [5]
5. LTSN 2003 Learning and Teaching Support Network (UK) – all graduates [7]

### Table 2. Main Transferable Skills [2]

Chemical engineering graduates are expected to be:
1. Good at communicating in a variety of forms (written, oral, etc)
2. Able to work well in teams
3. Able to solve problems (pro-actively and with initiative)
4. Numeraite and IT literate
5. Able to manage themselves and continue to learn

### 1.2 Transferable Skills of Graduates in General

The Higher Education Funding Council for England (HEFCE) published in 2001 a survey on ‘The employment of UK graduates: comparisons with Europe and Japan’ (HEFCE, 2001). [8] The graduates were asked to rate a list of 36 competencies according to the extent to which they possessed them on graduation, and the extent to which they were required in their current work. The differences in the results between UK and Europe were relatively small compared to the difference with Japan and, to keep the comparison simple, only the data for Europe and Japan is considered here.

Table 3 compares the top 10 competencies *possessed* at the time of graduation with the top 10 competencies *required* in current employment (as judged by the graduates themselves in both cases.) Comparing the perceptions of individual graduates about *required* and *possessed* competencies provides a means of identifying a *competency gap*
(when a graduate faces higher competence requirements than he or she possesses), and a competency surplus (when an existing competence of a graduate is not required by the employer to its maximum extent). The 10 most common competency gaps are shown in Table 4. The two most commonly cited competency surpluses were identical for both Europe and Japan; (1) foreign language proficiency; (2) subject-specific theoretical knowledge.

<table>
<thead>
<tr>
<th>Table 3. Possessed and Required Competencies of Graduates – Europe and Japan</th>
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<tbody>
<tr>
<td><strong>Top 10 Possessed Competencies</strong></td>
</tr>
<tr>
<td><strong>Europe</strong></td>
</tr>
<tr>
<td>1 Learning ability</td>
</tr>
<tr>
<td>2 Concentration</td>
</tr>
<tr>
<td>3 Work independently</td>
</tr>
<tr>
<td>4 Written communication</td>
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<tr>
<td>5 Loyalty, integrity</td>
</tr>
<tr>
<td>6 Specific knowledge</td>
</tr>
<tr>
<td>7 Involvement</td>
</tr>
<tr>
<td>8 Critical thinking</td>
</tr>
<tr>
<td>9 Adaptability</td>
</tr>
<tr>
<td>10 Tolerance</td>
</tr>
</tbody>
</table>

Based on our analysis of degree programme requirements and this general survey, it would appear that most transferable skills are being achieved.

1.3 Transferable Skills of Chemical Engineering Graduates

The World Chemical Engineering Council (WCEC) has undertaken a survey on ‘How Does Chemical Engineering Education Meet the Requirements of Employment?’ (WCEC, 2004). [9] This survey sought the views, on a worldwide basis, from young chemical engineers in the first five years of their professional employment. The aim was to make a comparative assessment worldwide of how well young chemical engineers feel
their education has prepared them for the requirements of their professional lives. The focus was on general skills and abilities, not the specific content of curricula. A total of 2,158 young chemical engineers from 63 countries had taken part in the survey by December 2003, and the majority of respondents had been in employment for over two years. In terms of the relatively large number of respondents, and their experience of their professional requirements, this gives an authoritative picture.

The survey included an analysis of where graduates were employed. A total of 27 sectors were identified, of which the main ones, on a worldwide basis, are shown in Figure 1. Chemical Engineering graduates are now employed across a wide range of sectors and it is essential that the transferable skills of the graduates are appropriate, both in terms of depth and breadth, for this diverse pattern of employment.

![Figure 1. Employment of Graduates](image)

A major part of the survey was to compare the graduates’ own assessment of the skills / abilities acquired during education with the relevance of these skills to their work. The specific question was ‘*Rank the following skills/ abilities with respect to the quality of*...
your education and its relevance to your work’. The rating was on a five point scale: 1 – very low, 2 – low, 3 – medium, 4 – high, 5 – very high.

The answers to this question are shown in Table 5, where the skills have been ranked according to their relevance to work.

<table>
<thead>
<tr>
<th>Generic Skills / Abilities</th>
<th>Education</th>
<th>Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Ability to work effectively as a member of a team</td>
<td>3.850</td>
<td>4.364</td>
</tr>
<tr>
<td>2 Ability to analyse information</td>
<td>4.053</td>
<td>4.323</td>
</tr>
<tr>
<td>3 Ability to communicate effectively</td>
<td>3.482</td>
<td>4.279</td>
</tr>
<tr>
<td>4 Ability to gather information</td>
<td>3.966</td>
<td>4.232</td>
</tr>
<tr>
<td>5 Self learning ability</td>
<td>3.937</td>
<td>4.232</td>
</tr>
<tr>
<td>6 Ability to solve problems</td>
<td>3.884</td>
<td>4.22</td>
</tr>
<tr>
<td>7 Appreciation of an interdisciplinary approach</td>
<td>3.524</td>
<td>4.028</td>
</tr>
<tr>
<td>8 Critical thinking</td>
<td>3.578</td>
<td>3.978</td>
</tr>
<tr>
<td>9 Ability to identify and formulate problems</td>
<td>3.564</td>
<td>3.972</td>
</tr>
<tr>
<td>10 Importance of a broad and general education</td>
<td>3.803</td>
<td>3.958</td>
</tr>
<tr>
<td>11 Expectation of the need for lifelong learning</td>
<td>3.433</td>
<td>3.950</td>
</tr>
<tr>
<td>12 Understanding of ethical and professional responsibilities</td>
<td>3.208</td>
<td>3.924</td>
</tr>
<tr>
<td>13 Ability to be a leader</td>
<td>3.155</td>
<td>3.834</td>
</tr>
<tr>
<td>14 Ability to apply knowledge of basic science &amp; chemical engineering fundamentals</td>
<td>4.063</td>
<td>3.754</td>
</tr>
<tr>
<td>15 Management skills</td>
<td>2.726</td>
<td>3.696</td>
</tr>
<tr>
<td>16 Ability to use a systematic approach to process and product design</td>
<td>3.367</td>
<td>3.614</td>
</tr>
<tr>
<td>17 Competence in information technology</td>
<td>3.339</td>
<td>3.596</td>
</tr>
<tr>
<td>18 Knowledge of methods for project management</td>
<td>2.401</td>
<td>3.365</td>
</tr>
<tr>
<td>19 Understanding of cultural diversity</td>
<td>2.812</td>
<td>3.332</td>
</tr>
<tr>
<td>20 Business orientated thinking / Business approach</td>
<td>2.275</td>
<td>3.332</td>
</tr>
<tr>
<td>21 Appreciation of the potential of research</td>
<td>3.576</td>
<td>3.242</td>
</tr>
<tr>
<td>22 Understanding of principles of sustainable development</td>
<td>2.671</td>
<td>3.196</td>
</tr>
<tr>
<td>23 Understanding of fundamental principles of financial management</td>
<td>2.604</td>
<td>3.141</td>
</tr>
<tr>
<td>24 Knowledge of methods for total quality management</td>
<td>2.186</td>
<td>3.063</td>
</tr>
<tr>
<td>25 Foreign languages</td>
<td>2.488</td>
<td>2.887</td>
</tr>
<tr>
<td>26 Knowledge of marketing principles</td>
<td>1.998</td>
<td>2.730</td>
</tr>
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</table>

It should be noted that a major difference between the rank for education and the rank for work is an indication of either a **skills gap** or a **skills surplus**. (This is the same methodology as used in the HEFCE general survey discussed previously.) **With the exception of only two skills, all of the skills are required to a greater extent at work than they are developed during education.** The two skills that are rated as more important during education than for employment are:

(14) **Ability to apply knowledge of basic science and chemical engineering fundamentals**;

(21) **Appreciation of the potential of research**.

These are, unsurprisingly, the traditional priorities of a classical university education.
The data in Table 5 also provides some other messages about other knowledge and skills gaps and where more emphasis within education on the following topics might be desirable: ethical and professional responsibilities; management and business; project management; sustainability; total quality management.

However, it is the difference in ranking in two particular skills that draws out some interesting and relevant lessons that we may have to consider here:

(7) Appreciation of an interdisciplinary approach
(15) Management skills

Both show large differences in scores and this will form the basis of the discussion in remainder of this paper.

1.4 Immediate Conclusions

The simplest overall conclusion from the available data is that, in general, the key transferable skills acquired by chemical engineering graduates during their education are perceived by the graduates themselves and by their employers as insufficient to meet the needs of employment. By contrast, the graduates’ knowledge of chemical engineering principles and their subject-specific skills are more than sufficient for their employment.

2.0 The Alternative Skills View

In 1971, J. Sterling Livingston, then Professor of Business Administration at Harvard Business School reported,

“Managers are not taught in formal education programmes what they need to know to build successful careers in management. Most management graduates prefer staff positions in headquarters to line positions.” [10]


“Considering the tremendous responsibilities senior managers face,. it is remarkable that their training and development has never been subject to the sort of thinking that would accompany the preparation of any other profession.”

and
“what research there has been into the effectiveness of an MBA cited H. Minztberg’s research that a chief executive with an MBA was no more likely to be successful than one without”

More recently in 2006, The Royal Academy of Engineering in their report into *The Engineering Graduate Today Educating Engineers for the 21st Century: The Industry View [12]* suggested:

Newly-recruited engineering graduates are used in a wide range of job roles. Whilst research and development, design and production/manufacturing are the most relevant activities within the sample studied, engineering graduates are to be found across the product lifecycle and throughout the value chain. As a result, many graduate engineers are likely to find themselves in roles which do not necessarily involve hands-on specialist engineering. To fill these roles engineering firms look for skills and attributes in two broad areas. The first is a set of defining skills that are unique to the engineer and which encompass the domain of technical skills. These include a sound knowledge of the engineering fundamentals within their discipline, built on a solid base of mathematics. Other highly sought-after attributes in this domain are creativity and innovation plus the ability to apply theory in practice.

The second skill set includes the social and interpersonal skills and attributes that enable the engineer to operate in a commercial working environment. These include communication skills, team-working skills, and business skills, which for entry-level graduates primarily mean awareness of the commercial implications of engineering decisions.

To conclude up to this point,

- We, the universities believe that graduates leave with appropriate transferable skills.
- The graduates believe that those skills meet their initial job requirements.
- There may be a gap in graduate skills in
  - *Appreciation of an interdisciplinary approach*
  - *Management skills*
- There remain industry doubts about this gap
- The conventional management training approach of MBA is open to criticism.

To move forward we therefore must look for any areas that we can draw on beyond this criticism of post graduate education and perhaps there is a message for Chemical Engineering Education and for Graduate Development Programmes from Company-based Projects in a Masters-level Programmes and in CPD provision generally which may address these issues since in general these programmes feature:

- A Graduate development programme– knowledge and skills are acquired
- Problems / challenges facing chemical engineering graduates / managers in industry are addressed.
The remainder of this paper therefore presents some ideas, but perhaps not all the answers to the issue of further training.

2.2 Background

Strathclyde University’s Masters programme for industry-based graduates – *MSc in Process Technology & Management* is an Integrated Graduate Development Scheme (IGDS) which is a post graduate course that attempts to provide career development for junior / middle technical managers and includes a substantial work-based project

The theme of IGDS Programmes were supported and encouraged by UK Research Councils with an objectives of providing:

- High-level training and development for graduate managers and technologists in particular industries – meeting the needs of industry
- Integration of technical / management/ business knowledge and skills- adding key skills
- Flexible delivery by short courses and/or distance learning – minimum ‘time-off-the–job’

2.3 Why an Integrated Approach?

This approach appears to have been generated on the basis of:

“*Employers want graduates who are… able to communicate, share their skills, and appreciate their place in a wider organisation*”

“*Those graduates with technical degrees lack the important personal skills*”

Institute of Employment Studies Report

Strathclyde University IGDS programme has three main subject areas where the Technology Modules have significant priority areas for Chemical & Process Industries:

- Cleaner, safer, more profitable processes
- Complex processing – e.g. multi-phase

and cover the following subjects

| Clean Processing                  | Safety & Environment             |
| Modelling & Simulation            | Process Design Methods           |
| Process Control Strategies        | Multi-Phase Processing           |
| Advanced Separations              | Manufacturing Technology          |
The Management and IT Modules are core features of an MBA but here are industry specific:

Accounting and Finance Management Functions
Project Management General Management
Financial Management

IT Strategy Database Management
Software Project Management

and the Teaching and Learning Methods are:

• Text-based self-study material with self assessments
• Some internet-based delivery
• Assignments – usually work-based that as a consequence
  - develop problem solving skills
  - reinforce applications to the company

However it is the Major Project which represents a “difference” from other post graduate programmes and particularly pure MBAs, and this paper in reaching its final conclusion will draw on evidence from that activity.

In trying to evaluate the effectiveness of these industrial based Masters Training Programmes, such as IGDS, it is of interest to course funders & providers to review the effectiveness as a whole of these forms of programmes. Since they were based around a principle of CPD and industrial relevance, what interests us most are the deliverables at the end of the course.

As such, it is “impact” that we would like to measure rather than “did you enjoy the lecture?”

To assess impact, Kirkpatrick’s [13] four levels of evaluation of the training program is considered to be relevant, i.e. consisting of

(1) Reaction, (2) Learning, (3) Behaviour, & (4) Impact or Results

The results we developed in 2002 [14] suggest some interesting outcomes for the evaluation score “impact in companies”, in that there is a higher score for Technology & Management graduates than MBA graduates. For the MBA graduates, the survey seems to suggest that the main difference in the results, is this “lack of impact” in their workplace and the only “best” workplace application for MBA students comes from a move into consultancy and becoming “experts” – very much a return to Livingston’s view perhaps.

The following charts details these findings:
Moving a stage further in reviews of student performance in the Major Project, and its integrating application across the three subject areas of Process Technology, IT & Management, during the course development, we noted in some individuals that they seemed to fail to link the importance of the firm’s technology drivers with its overall business objectives. Therefore, in the development of the Major Project guidelines, we asked the students to:

• Extend themselves in challenging and open-ended work
• Apply their enhanced knowledge of process engineering, business and IT
• Develop additional specialist knowledge and skills in other areas
• Benefit their employers

Students are required to develop their own project scope and proposal against guidelines which can be summarised as meeting two main criteria:

1. Company’s current technical and business challenges
2. There real impact on the business’s future

The Major Project is structured in two parts:

The Management Report which is a summary of conclusions and recommendations and includes:
• Analysis of strengths / weaknesses of current position
• Costs / benefits of implementing the proposals
• Plan for implementing the proposals

The second part is the Research Report which provides the detailed analysis of the project scope and technical findings.
It is however the Management report that demonstrates difference here and the reason behind the improved “impact” results and the remainder of this paper looks at the detailed analysis of 63 project reports, taken from a variety of Industry Sectors and is shown below:

**Industry Sectors**

![Industry Sectors Pie Chart]

- Speciality Chemicals
- Pharmaceuticals
- Energy
- Oil and Gas
- Environmental
- Other

Fig 3 Breakdown of Major project by industry sector

Looking first at **Types of Project**, they include

**Environmental**
- Decommissioning of offshore oil and gas facilities
- Evaluation of effluent treatment options

**Cost Reduction**
- Refinery scheduling – development of dynamic model
- Improved nitrogen generation facilities for purge gas

**Human Resources**
- Skill pool management in an ageing workforce

**New Product Development**
- Business case and preliminary design for a new pilot-plant facility
- Critical review of the new product development system

**Process Development**
- Practical implementation of SPC
• **Technology Transfer – the role of Co-Development between research and manufacturing**

and some Project deliverables have meaningful impacts on their companies are:

• **Reduction in environmental discharges**

• **Avoidance of prosecution**

• **Yield improvements**

• **Improved methods of introducing new processes**

• **Reduction in “time to market”**

• **Better understanding of customers’ technical demands**

We now need to ask whether these outcomes needed to draw from the use of knowledge and skills developed in the programme since most projects require multi-skills approaches. Perhaps a guide can be drawn from the students’ choice of Elective modules.

Those with a **High demand** are:

• **Individual Process Engineering Skills**
• **Financial Management**
• **HR Management**

and with **Medium demand** are

• **Manufacturing Technology**
• **Marketing**

whereas those with **Low demand** are the

• **IT Options**

This selection of modules during the three years of the course mirrors the knowledge and skills used across these projects undertaken at the end of the course and suggest that the key outcome here is that our course delegates as engineers recognise that need to understand Finance, HR, and the External Environment to be successful in their organisations.
2.4 Conclusions

This type of integrated Masters Programme:

• Forces a multi-disciplinary / multi-organisation approach on students

• Uses work-based assignments to build competencies

• Provides support in career development

• Delivers measurable paybacks to sponsoring organisations

Is This Approach New?

We would like to think that the idea of ‘the engineer as a man of business’ is a slightly different approach in our Integrated Masters programmes, but…..

“During the first decade of the 20th century, Dr Alex C. Humphreys, the President of the Stevens Institute of Technology, the privately endowed college of engineering and science described above, was also a successful practicing engineer of high standing. He gave an address on ‘Business training for the engineer’ in which he began with an
axiom: “Self-evident should be the truth of the proposition that the engineer ought to be a man of business, or at least informed of, and prepared to conform to, business conditions and business methods. Businessmen bankers, and manufacturers not infrequently refuse their confidence to engineers and experts as a class, because, under trial, some individuals have demonstrated their incapacity to meet business conditions; from the standpoint of the man of business their reports, advice, conclusions have required interpretation and readjustment or amendment. The man, so far somewhat exceptional, who is able to bring to the service of clients or associates a sound technical training and the ability to meet business conditions, proves by his comparative success the material value of this dual capacity. For the sake of the profession and the country at large it is important that this broader capacity should no longer be exceptional” [15]

Is there a lesson most industries still have to learn, that engineers are only multi-disciplinary if they have business skills too. It’s a lesson that academia seems to have been saying and offering, and perhaps still a challenge for industry to take up.
3.0 References  
[1] FORTENBERRY N. “Modern Skills for Engineers” Prism July 2006 ASSE  
[10] J STERLING LIVINGSTON “Myth of the well-educated manager”, HBR Jan-Feb 1971, No 71108:  

*Source: Addresses to engineering students (Waddell and Harrington, Consulting Engineers, Kansas City, Missouri, USA, 1911)*