Is the mathematics problem recognised by the chemical industry?

Paper

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The Mathematics Problem in Chemistry, as recognised by academics, is not present to any great extent in the United Kingdom chemical industry. Although the mathematical skills of many chemistry graduates are deficient in some areas, such employees are still seen by employers as being essentially numerate. Mathematical requirements in the industry are often low, and can be enhanced by the use of computers. Many employers place great emphasis on statistical techniques, and this and other applications of mathematics are seen to be lacking to some extent in mathematics courses provided to chemists at university.

Introduction

The key skills agenda is now well established within higher education. The National Committee of Inquiry into Higher Education[1] of 1997 recognised a number of such skills: communication, numeracy, the use of information technology and learning how to learn. It is probably true that most chemistry undergraduate programmes have evolved in recent years to encompass these. For example, communication skills are now widely taught through a variety of approaches in such courses.

Student deficiencies in numerical skills have been recognised widely among the science and engineering disciplines. A report[2] from the Royal Society in July 1997 made a number of recommendations about the teaching and learning of algebra at the pre-university level, and more recently a joint seminar[3] was held by the Engineering Council, the Learning and Teaching Support Network, the Institute of Mathematics and its Applications, and the London Mathematical Society to discuss the 'Mathematics Problem'.

While poor mathematical skills may be seen as more of a problem by the bodies listed above than by chemists, there have also been concerns among physical chemists in particular for some time. This is evidenced by a meeting on the subject held by the Royal Society of Chemistry in 1996 and by a series of meetings for both chemists and physicists organised by the LTSN Centre for Physical Sciences. A number of chemists have written papers on the subject[4, 5], and produced textbooks designed to meet the needs of chemists rather better than more generic offerings.

The study reported in this paper was carried out in order to ascertain whether the perception in academia of the poor mathematical skills of chemists is shared by those in the chemical industry employing chemistry graduates. While many such graduates do find employment elsewhere, the needs of this well-defined group of employers are thought to match most closely the professional aims of chemistry degree courses. The key skill of numeracy was not explicitly included in a survey of chemistry graduates[6] reported in 1999.

Methodology

Suitable employers were identified from the database of the Chemical Industries Association.[7] A pilot study was performed by e-mail, which involved sending out 178 questionnaires. In the light of responses very slight changes were made to the questionnaire. The final version (Figure 1) was sent by regular mail to a further 386 employers, marked for the attention of the Graduate Recruitment Officer.

Results and Discussion

A total of 110 completed questionnaires were returned, 12 in response to the e-mail version and 98 in response to the paper version. This represents response rates of 7% and 25% respectively, with an overall value of 19.5%. The number of useful replies is felt to be

Figure 1. Final version of questionnaire.

QUESTIONNAIRE

1	Approximately how many graduates of chemistry (or chemically related) does your organisation employ?	
2	Has anyone in your organisation ever expressed concern about the mathematical ability of graduate chemists?	Yes/No
3	Do you screen chemistry graduates on the basis of the mathematical skills as part of your selection process?	Yes/No
4	Do you consider that, on the whole, chemistry graduates can be described as numerate?	Yes/No
5	Please rate how essential you would regard possession of mathematical skills in the following areas: Statistics Calculus Algebra Arithmetic	 Essential/Useful/Not required Essential/Useful/Not required Essential/Useful/Not required Essential/Useful/Not required
6	Are there any other mathematical skills which chemistry graduates typically do not possess?	
7	Does your organisation provide training in mathematical skills for chemistry graduates you employ	Yes/No
8	Do you believe that universities are generally aware of the mathematical skills industry expects their chemistry graduates to possess	Yes/No
9	Do you believe that time spent on mathematical training in chemistry degree courses would be better spent?	Yes/No
10	If YES, in which areas should this time be spent?	
11	Please add any comments you wish to make about the mathematical ability of the chemistry graduates you employ	
12	Finally, could you please provide some brief details about yourself Name: Position in Organisation: Company name:	

sufficient to give meaningful results across a range of companies. These employed a total of 2958 people with the average size of 27 employees. Questionnaires were completed by company representatives holding a variety of job titles, including managing director, process improvement manager, research and development manager, general manager, technical manager, marketing director, operations director, business manager, human resources director and operations general manager.

Figure 2. The sizes of companies included in the survey.

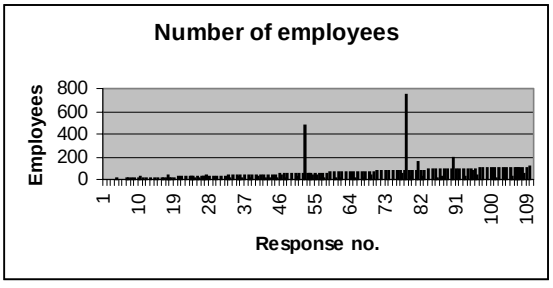


Figure 2 shows the spread of the number of chemistry graduates in each company surveyed. There is clearly a bias towards smaller companies, but the survey did cover employers of approximately 3000 graduates of chemistry or related subjects. Some respondents made the point that they were part of a much larger organisation. For example, in one case it was stated that

the small number of graduates in the United Kingdom branch were expected to demonstrate the same level of mathematical competence as their counterparts in the parent organisation in Japan. The responses also included those who don't employ chemistry graduates directly, but have experience of them through contracted out work and were therefore able to provide useful information.

The responses to question 2 show that only a small number (18 or 16%) of employers reported any explicit concern in the mathematical ability of graduate chemists. If these results are weighted according to the number of employees, however, the proportion shrinks to only 10%. It is likely, of course, that the number of specific instances of concern will be rather lower than this, assuming that mathematical ability is not spread evenly across the chemistry graduates in an organisation. It is interesting that the organisations expressing concern were those of low to medium size; the maximum number of chemistry graduates was 40 amongst those employers with a positive response here.

That the 'Mathematics Problem in Chemistry' is not apparently recognised by the chemical industry is an interesting result, although perhaps not too surprising if they are able to be reasonably selective. However, some of the free response answers to be reported later do suggest that there are concerns that are not apparent from the responses to this question.

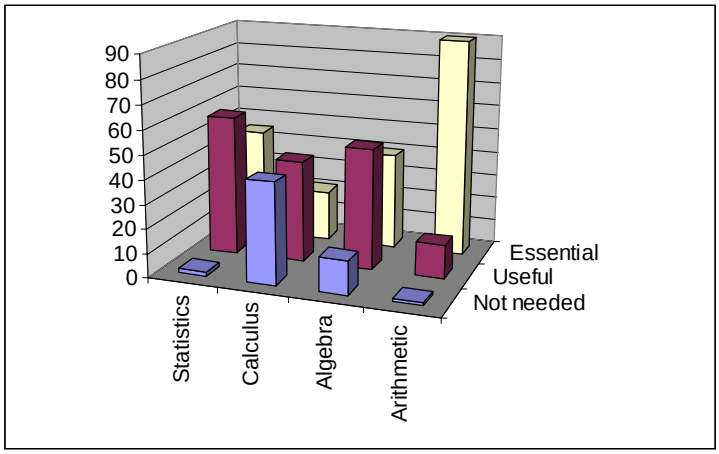
The overwhelming number of responses (97) indicated that employers do consider chemistry graduates to be numerate. Not surprisingly, of the small number of negative responses to this question five also belonged to the group who had expressed concern about mathematical ability. These findings suggest that the marketing of chemistry as a numerate discipline is still valid; this may also be important for those graduates who go into numerate non-scientific careers such as accountancy.[8]

Figure 3 summarises the responses that rated statistics, calculus, algebra and arithmetic as not needed, useful or essential. It can be seen that arithmetic was regarded as the most essential skill, with statistics next. Not too surprisingly, the skill that was felt likely to be of least use was calculus, although one respondent made the point that both calculus and algebra are useful for building concepts. Another surprising result from this section of the questionnaire was that 13 respondents felt that all four skills were essential. This group represented companies employing 254 chemistry graduates, and suggests that a minority of companies do have high mathematical expectations of their graduates.

The majority of respondents felt that the areas outlined above did cover all of the mathematical skills they might wish chemistry graduates to possess. However, when asked if there were additional areas, 5 respondents mentioned statistics again, suggesting that this is an area of particular concern. In addition, data manipulation and the quoting of values to acceptable levels of precision are related areas that were mentioned. Other suggestions were: estimation, basic numeracy, equations describing a straight line, physical modelling, geometry, mental arithmetic, and mechanics. The need to be able to apply mathematical knowledge, for example in setting up spreadsheets, was also mentioned. An additional area, probably not taught in most basic mathematics for chemistry courses, was working with commercial business data.

Twelve of the organisations surveyed did provide some mathematical training themselves, although in several cases this was restricted to statistics. These were split almost evenly (seven to five) between those who had expressed concerns about mathematical ability and those who had not. A clear majority (sixty-four) did believe that universities were generally aware of the mathematical skills industry expects their chemistry graduates to

Figure 3. Employers' perceptions of the importance of categories of mathematical skills.



possess, with only twenty-nine believing that this was not the case.

The question on how the time currently devoted to mathematics courses for chemists could be better spent was answered in a number of ways. Three respondents (who had not had cause for concern about mathematical ability) identified various aspects of chemistry to fill this time. The opportunity to mention statistics again here was taken by twelve respondents, emphasising that this is seen as a very important area. This was tied to applications of statistics and the use of appropriate computer packages in some responses. Seven respondents mentioned applications of the basic mathematical material, and another mentioned stoichiometric calculations specifically. Other mathematical techniques mentioned once each were arithmetic, simultaneous equations, and algebra. One respondent suggested that courses should be run at a lower level, but that mastery at that level should be ensured. This raises a more general point about the level of skill necessary to achieve a pass in a given module, but studies in the area of medicine have failed to produce information on this.[9]

When asked to make any other comments about the mathematical skills of chemistry graduates, the group who had noted concerns in this area described abilities as variously 'fairly good', 'adequate' and 'not particularly good'. Weaknesses in statistics were noted by two of the respondents, and one noted that graduates were very competent in arithmetic, but less so in other areas. A specific example of a problem was the case where a graduate could not immediately see why reporting the result of a titration calculation to five significant figures was wrong. One respondent felt that basic mathematical ability should be ascertained before admission to chemistry degree courses and that this was clearly not the case. One suspects that admissions tutors would be delighted to be able to do this, but that in the current climate this would not be a sensible strategy in terms of student numbers.[10] More pessimistically, another respondent believed that newly qualified graduates were not ready for any form of employment. This general statement needs to be put in the context of the individual mission statements of higher education institutions that seek to address the question of graduate employability in different ways.[11]

The group of respondents who had not expressed any concerns in this area described the mathematical ability of their chemistry graduates as varying from 'poor to middling' to 'normally excellent'. Three respondents highlighted deficiencies in statistical methods as problematic, and the inability of many graduates to perform simple standardisation calculations was mentioned. One respondent mentioned that arithmetic is often poor and skills in mental arithmetic are non-existent. It was noted that organic chemists tend to stay away from and lack confidence in mathematics, but deficiencies may become apparent when graduates are employed as process chemists. One respondent suggested that mathematical deficiencies were more likely to be in the general arithmetical skills of part time degree students.

While these responses may at first sight seem surprising from this group of employers, further comments do shed light on why such deficiencies in mathematical skills may not be problematic. Several noted that they only require fairly basic mathematical skills, such as working out molar ratios and percentage yields, converting mass into amount of substance, and calculating heats of reaction from bond energies. One respondent also noted that much of the basic arithmetic required is now performed by automated equipment and computers. Two respondents noted that specialised mathematical skills would be bought in as required; one did, however, qualify this by stating that it is useful for someone to be able to review the underlying mathematics of large projects. One also felt that chemistry graduates were able to learn what they didn't already know in this area, suggesting a certain level of mathematical skill as opposed to knowledge. This also suggests that the chemistry graduates concerned are able to 'learn how to learn' as envisaged by the National Committee of Inquiry into Higher Education[1].

Some of the more general comments backed up the findings reported in the previous paragraph. Several other skills were felt to be more important than mathematics; those mentioned were computer literacy, chemical knowledge, practical skills, teamwork and communication. One respondent noted that the improvement in computer literacy in recent years has led to the more effective analysis of data through the use of computer packages. It is also evident that there are other problems too. Poor English was felt to be a more important problem by one respondent, and another was far more concerned about the

chemical ability of chemistry graduates in the United Kingdom.

Conclusions

A very low proportion of the companies surveyed expressed concern about the mathematical ability of the chemistry graduates they employ. Chemistry graduates are still seen by the overwhelming majority as being numerate, so this aspect of the marketing of such degrees is still valid.

Arithmetic is seen as an essential skill by most employers, but many also require statistics and deficiencies in this area were often highlighted. Higher level mathematical skills involving calculus are regarded as useful by around half the employers surveyed, and as essential by some, suggesting that such topics should be retained in mathematics for chemistry courses. There are calls for more applications of mathematical knowledge to be taught, which may provide support for the teaching of such courses by chemists rather than by mathematicians.[12]

Many employers require only basic mathematical skills, and automation procedures may even remove much of the need for these. Some employers do see the effective use of computer software as having improved the extent to which students are able to perform mathematical tasks. Higher level skills can be bought in as required. Deficiencies in English and even in chemical knowledge are seen as being of more concern than those in mathematics.

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