Skills in Mathematics and Statistics in Chemistry and tackling transition

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The Higher Education Academy

The Higher Education Academy STEM project series

Contents

Foreword

This report is one of a series of reports commissioned by the Higher Education Academy STEM team to look at mathematical and statistical skills in a range of discipline areas. The report seeks to contribute to existing knowledge about this area within the context of Chemistry.

At the start of the study, a list of areas for consideration was provided by the Higher Education Academy. These encompassed the way in which mathematical and statistical skills form part of the discipline landscape, the signalling higher education provides about the need for these skills, sector requirements within the discipline (e.g. from accreditors and Quality Assurance Agency subject benchmark statements), the use of diagnostic testing and the support provided for students to improve and develop their mathematical and statistical skills. The methods used in the study in Chemistry consisted of (i) a literature review; (ii) survey work; and (iii) a discussion event.

The mathematical requirements of a Chemistry degree are quite demanding. However, the actual mathematical entrance qualifications for Chemistry degrees can be comparatively low. This disparity provides particular challenges in Chemistry which have been recognised for a long time. Despite the development of many relevant teaching resources there has been little research on this topic. The present study aims to address this issue and to provide a sound evidence base to inform future discussion, policy developments and teaching practice in the discipline.

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Foreword

From thermodynamics and kinetics to quantum mechanics, mathematical language provides insight into all branches of Chemistry and can form the basis of a chemist's ability to understand unfamiliar concepts, construct models and solve problems.

However, admission requirements to Chemistry degree programmes rarely reflect this need for a solid mathematical foundation. The individual responses of different academic institutions to address this have resulted in a variety of solutions. At the same time, a lack of research into the effectiveness of these different approaches has made it difficult to produce a coherent, sector-wide strategy to tackle this problem.

The Royal Society of Chemistry has long recognised the importance of addressing the issues in this area, producing textbooks, articles in our journals and magazines and online resources that support both academic institutions and the students themselves. We were therefore pleased to lend our support to this Higher Education Academy project and welcome this report and its clear recommendations of how the Chemistry community can move forward and support the next generation of chemists.

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1 Summarised findings and recommendations

1.1 Introduction

Chemistry degree programmes typically include a number of topics than can only be described in terms of relatively sophisticated Mathematics. These include the traditional areas of thermodynamics, kinetics, quantum mechanics and statistical mechanics and newer ones such as computational Chemistry. A thorough grasp of calculus is required in order to develop proficiency in these areas. In order to develop this, students also need to be proficient in areas such as algebra, functions and trigonometry. In contrast, relatively little Statistics is required for the study of Chemistry beyond a knowledge of simple statistical descriptors.

On the other hand, most programmes have very modest admission requirements in the area of Mathematics, rarely going beyond the university requirement of a GCSE pass at grade C. There are a number of exceptions to this, but most departments have been required to put strategies in place to address the mismatch between these requirements and their students' mathematical achievements on entry. This has generally involved running Mathematics for Chemistry modules in-house or requiring students to attend service modules run by the Mathematics department in the institution.

Related to this, a number of chemists have written textbooks to support students in this area and magazine articles on relevant teaching techniques have been produced. Electronic resources have also been developed over a number of years by various groups including the Royal Society of Chemistry. A limited amount of research in this area has also been published. The Higher Education Academy (HEA) Science, Technology, Engineering and Mathematics (STEM) project was undertaken to draw together the research findings and to provide an evidence base on the problem and on Mathematics-related issues encountered by students at the transition from pre-university to degree programmes in Chemistry.

A literature review was undertaken at the start of the study, and three surveys were developed to follow on from this. One survey was aimed at staff teaching within Chemistry and a second survey was directed at heads of department or those with responsibilities for organising teaching in Chemistry (taken together these form the HEA STEM staff survey). The third survey was for students taking degree programmes within Chemistry. All of the surveys were developed within the full HEA STEM project team to ensure that, as far as possible, a consistent approach was adopted to the work across the full spectrum of disciplines involved in the work. The surveys were in circulation in the Spring and early Summer of 2013. The last strand of the work was a set of HEA STEM Tackling Transition events for the various disciplines. The Chemistry event provided an opportunity for staff working in Chemistry in higher education to meet and discuss the areas of interest with colleagues in the pre-university sector and other key stakeholders in the discipline. The discussions were recorded and collated with the other data obtained during the work.

1.2 Findings and recommendations

1.2.1 Notable findings †

1. Lack of confidence was the most commonly cited barrier to studying Mathematics by respondents to the HEA STEM student and staff surveys. This is also frequently cited in relevant literature.

2. In the HEA STEM student survey about half of respondents believed that the gap in studying Mathematics before their degree programme contributed to their difficulties in studying Mathematics; with a slightly smaller proportion of staff respondents also believing this to be the case.

3. In the HEA STEM student survey over a quarter of respondents claimed that the relevance of Mathematics to Chemistry had not been explained to them. In addition about one third of respondents had found more Mathematics than expected in the degree programme.

4. In the HEA STEM staff survey the majority of respondents believed that there is a wide range in the mathematical skills of students. In the HEA STEM student survey about a quarter of respondents said that they found Mathematics always or usually difficult.

5. The Quality Assurance Agency (QAA) subject benchmark statement for Chemistry contains little specific detail on required mathematical skills. This is in contrast to the equivalent statements for Astronomy and Astrophysics, Forensic Science and Physics. Delegates at the HEA STEM event called for a clear statement of the mathematical skills required for the study of a Chemistry degree programme.

6. Delegates at the HEA STEM event agreed that grade C GCSE Mathematics provided an insufficient basis for a study of degree level Chemistry but thought that insisting on an A-level in Mathematics would not provide a solution.

7. In the HEA STEM student survey about 20% of respondents reported that they had undertaken diagnostic testing in Mathematics at the start of their Chemistry degree programme. In the HEA STEM staff survey about a third of respondents reported that diagnostic testing took place in their degree programme.

8. In the HEA STEM staff survey almost all respondents reported that Mathematics modules were run in Year 1 of Chemistry degree programmes.

9. In the HEA STEM student survey the majority of respondents reported that they had not accessed the additional Mathematics support that was available. Delegates at the HEA STEM event reported that there was a reticence of students to engage with the materials that were available.

10. Delegates at the HEA STEM event expressed support for a new post-GCSE qualification in Mathematics. However, the literature notes that prior Mathematics experience is only of limited help in preparing students for a study of Chemistry.

† The participants in the HEA STEM surveys and events were self-selecting and in some cases the sample sizes were quite small. Detailed information on sample sizes and the response rates for specific questions is given in Section 4.

1.2.2 Recommendations

1. Higher education institutions and professional bodies in Chemistry should provide clear signalling to the pre-university sector about the need for mathematical work in Chemistry degree programmes. Promotional literature and information about Chemistry degree programmes should explain how mathematical skills will be developed through the programme.

2. The QAA subject benchmark subject benchmark statement in Chemistry should be revised at the earliest opportunity to include specific information on the type and level of mathematical knowledge and skills that should be present in Chemistry degree programmes.

3. University staff with responsibility for managing degree programmes in Chemistry should review their approach to, or consider introducing, diagnostic testing of students' mathematical knowledge and skills at the start of Chemistry degrees, and use the results to inform feedback and other follow-up actions.

4. Students on university degree programmes in Chemistry should be provided with information about all the resources and opportunities for support with their mathematical skills development and university staff in Chemistry should actively and regularly encourage students to use the available resources and opportunities.

5. Key stakeholders in the Chemistry discipline and university staff with responsibility for managing degree programmes in Chemistry should actively engage with current and future developments in post-16 qualifications in Mathematics (e.g. A-level Mathematics, "Core Maths").

2 Background

It is generally accepted that mathematical skills at GCSE level or equivalent are used extensively in all UK Chemistry degree programmes at BSc and MSc level. In addition, all such programmes refer to aspects of topics that are usually covered in post-16 Mathematics qualifications (A-level or equivalent in the UK) such as calculus, matrices, vectors and statistics. Mathematics is therefore an essential tool in a UK Chemistry degree programme (Sutherland and Dewhurst, 1999). However, many students are admitted to a degree programme in Chemistry in the UK without A-level Mathematics or an equivalent qualification, leading to the so-called "Mathematics Problem" (Engineering Council, 2000). This is a term that has been used to identify a serious decline in the mastery of mathematical skills by students embarking on mathematically based degree programmes. The term was initially used in relation to degree programmes in Engineering, Mathematics and Physics but was soon being used across the STEM subjects. It has since also been used in the context of the social sciences (Marr and Grove, 2010).

Universities and Colleges Admissions Service (UCAS) data shows that a GCSE Mathematics or equivalent qualification is required for all Chemistry programmes at an attainment level of at least grade C (although this is also a basic requirement for many non-science programmes). Some require a B grade at GCSE or equivalent (five institutions for UCAS code F100 and four for F103) or an A grade at GCSE or equivalent (two institutions for UCAS code F100 and two for F103). Four institutions require A-level Mathematics or equivalent for both the F100 and F103 programmes and one requires AS-level Mathematics or equivalent.

The QAA subject benchmark statement for Chemistry (Quality Assurance Agency, 2007) lists "numeracy and mathematical skills, including such aspects as error analysis, order-of-magnitude estimations, correct use of units and modes of data, presentation" under the generic skills required in Bachelor's degrees with honours and Masters programmes.

The body that accredits degrees in Chemistry in the UK is the Royal Society of Chemistry (Royal Society of Chemistry, 2012). Here, the required transferable skills are cross referenced to the generic skills outlined in the Chemistry subject benchmark statement at BSc and MChem level. Such skills are described as a key requirement for accreditation which universities must demonstrate. No list of numerical or mathematical skills is given in the documentation, although the Royal Society of Chemistry has previously produced a list of such guidelines (Royal Society of Chemistry, 1996).

The Royal Society of Chemistry (2009a) expressed the view that there is a problem with undergraduate Chemistry students' grasp of Mathematics and have set in place schemes to support mathematical skills at undergraduate level. These include the tutorial texts *Maths for Chemists* (Cockett and Doggett, 2012) which sold 3,800 copies in a previous edition, the *Maths Resource Database* (Royal Society of Chemistry and the Higher Education Academy, 2009), an extensive survey of the available resources, and a regular column in *Education in Chemistry* magazine (most recently Yates, 2013). Furthermore, several Chemistry textbooks have been published in the last 15 years (Yates, 2012) to address this gap in knowledge. The *Discover Maths* suite of resources has also been developed by the Royal Society of Chemistry in partnership with Pfizer (Royal Society of Chemistry, 2009b). These books and resources are helpful, but students still need some support and feedback to work through the material.

Attempts have also been made to build virtual communities of those involved in teaching Mathematics for Chemistry. These have included a Jiscmail list and a list hosted on the Royal Society of Chemistry's MyRSC system. Like many such initiatives in other areas, these were initially well supported but it proved difficult to maintain this initial momentum.

3 Research objectives and methodology

This report is based on three main activities undertaken in the HEA STEM project: a literature review; surveys of both staff and students; and a Tackling Transition event. The objective was to gather information about the "Mathematics Problem" in the Chemistry discipline at both the transition between school or college and university and during Chemistry degree programmes.

3.1 Literature review

There is a relatively small number of journals in chemical education, and these were searched for articles of relevance to the current topic. As well as papers which explicitly mentioned Mathematics in their title, more generic papers on skills development were considered. A list of more general papers of potential relevance was made available across the disciplines, and was examined to identify those of most relevance to Chemistry. A number of independent reports in the subject area were also examined for relevance. Finally a search was undertaken using keywords based on Chemistry and Mathematics. No restriction was placed on date and useful papers from as far back as 1975 were included. Resources reviewed were either from peer reviewed sources or reports from established bodies.

3.2 HEA STEM staff and student surveys in Chemistry

Three surveys were administered, two to staff (to heads of department and other teaching staff) and the other to students. In the former case a distinction was made between responses from heads of department and other teaching staff due to the potentially different perspectives of each, and where the responses are considered together it is described as the HEA STEM staff survey. In both cases the questions were developed by the HEA STEM project team. The questions used in the Chemistry surveys were tailored to the discipline in terms of language and likely mathematical content.

The surveys were administered in the form of online questionnaires. Links to these were distributed via the HEA Physical Sciences mailing list and via databases of staff and students held by the Royal Society of Chemistry. The survey was also advertised in the HEA Physical Sciences newsletter and by messages on the Jiscmail Physci-education mailing list. Staff were encouraged to make their students aware of the relevant survey in these cases. The staff survey was live from 28 February to 3 May 2013 and the student survey from 24 May to 28 June 2013.

Responses were received from 39 staff, of whom 8 were heads of department, and 721 students. The staff responses represented 31 individual institutions; in three cases there were responses from both a head of department and another member of teaching staff in the same institution. Staff responses were received from four institutions in Scotland while student responses represented three Scottish universities and a total of 18 across the UK. There are approximately 65 universities that teach Chemistry within the UK. Of the lecturers who responded to the staff survey, 20 of 22 (91%) reported that they had experience of teaching Mathematics within their degree programme during the last five years. The heads of department were not asked this question. The potential bias introduced from the proportion of non-heads with recent mathematical teaching experience should thus be noted.

3.3 HEA STEM Tackling Transition event in Chemistry

A meeting was held to obtain the views of stakeholders from sector bodies. This was attended by seven members of university teaching staff, four A-level teachers, one exam board representative, four members of Royal Society of Chemistry staff, three members of HEA staff and one independent consultant. The meeting began with introductory talks from members of the HEA STEM project team and was followed by a structured discussion in three groups each led by a facilitator. The groups were asked to consider what mathematical skills were needed in year one at university, where those skills were taught, and what could be done to ease the transition from school to university in the context of mathematical skills.

4 Main findings

4.1 Literature review

Many papers on misconceptions in Chemistry, that have a mathematical focus, note that students find difficulty relating symbols used in Chemistry with those used in Mathematics (Childs and Sheehan, 2009; Madden *et al*., 2011; Regan *et al*., 2011; Becker and Towns, 2012; Naah and Slanger, 2012). Several researchers have shown (Pickering, 1975; Ozsogomonyan and Loftus, 1979; Andrews and Andrews, 1979; Wagner *et al*., 2002; Tai *et al*., 2005; Tai and Sadler, 2007; Seery, 2009; Potgieter *et al*., 2010; Clifton *et al*., 2012) that the best indicator of Chemistry grades in undergraduate programmes is not the students' incoming Chemistry qualification but their incoming Mathematics qualification. Leopold and Edgar (2008) have shown that at undergraduate level Chemistry, mathematical performance is positively correlated with success in Chemistry, while Loehr *et al*. (2012) looked at the effect of Mathematics on incoming Biology graduates and also saw a strong positive association between mathematical experience and success on the course.

Interestingly, a survey reported by Yates (2002) of industries that employed Chemistry graduates suggested that mathematical skills were considered to be satisfactory. While some industries said that numeracy was a problem they were in the minority. One of the possible reasons cited by Yates for the lack of a problem in numeracy is that many industrial processes are automated and calculations are not carried out from scratch by the graduate. The weaker statistical skills of Chemistry graduates were noted in the survey (Yates, 2002), which is unsurprising given that students are unlikely to have encountered Statistics beyond that which is taught up to age 16. It has been clear for some time and reiterated in the recent SCORE (2012a, 2012b) reports on Mathematics content in A-level Chemistry, that mathematical tools beyond those taught within GCSE Mathematics or its equivalent qualifications are required to cope with an undergraduate degree in Chemistry and indeed A-level Chemistry. Shallcross and Walton (2007), an academic in Chemistry and a secondary school Mathematics teacher, have surveyed Mathematics GCSE and A-level courses and compared them with the Mathematics skills required for a degree in Chemistry. The conclusion is that an A grade at GCSE or its equivalent is the real minimum qualification required if A-level Mathematics cannot be offered. Childs and Sheehan (2009) carried out a survey of Chemistry students in Ireland, where the situation might be assumed to be broadly similar to that in the UK, and one of the two factors that emerged as having a significant effect on students' perceptions of difficult topics in Chemistry was mathematical ability. It hampered confidence in the laboratory (e.g. preparation of solutions, calculations of moles, purity etc.) and in physical Chemistry topics, e.g. thermodynamics, spectroscopy and kinetics. Students reported that they tried to avoid questions with Mathematics content.

Scott (2012) carried out a study where fifth year Scottish high school students were given a set of Chemistry questions and their analogous Mathematics questions. The study concluded that for the easier questions there was no significant difference in performance and that poor scores demonstrated a lack of a basic understanding of fundamental mathematical operations such as division and multiplication. However, the worrying result of the work of Scott (2012) is that a non-negligible number of students lacked confidence in very basic Mathematics skills, which has been shown to be a barrier to large parts of undergraduate Chemistry programmes and erode confidence (Childs and Sheehan, 2009; Potgieter and Davidowitz, 2011).

Becker and Towns (2012) develop further the idea of two modes for tackling Mathematics problems in a Chemistry context, i.e. algorithmic or recall and intuitive reasoning. Indeed, their study agrees with that of Scott (2012) in that prior mathematical ability did not necessarily mean that students would be able to tackle a variety of mathematical problems in the context of Chemistry. Becker and Towns (2012) suggested that one way to overcome these problems is group problem solving, one of the facets of the course described by Shallcross (2006). Here, students can learn from each other and see a variety of strategies that may be used to solve the same problem. This has the potential to persuade students that there is more than one approach to solving this type of problem. Scott (2012) has concluded that an algorithmic approach to the teaching of Mathematics needs to be overcome in order to achieve this.

Hanson and Overton (2010) surveyed recent graduates to ask questions about what had been useful in the Chemistry programme that they had studied and what the graduates would have liked more of, given that they were now in the early stages of a career. Around 85% of all graduates surveyed said that the numeracy and computational skills they gained were useful after graduation (the fifth most popular) and around 75% said that skills gained in the interpretation of experimental data were useful (the ninth most popular).

Although no study was identified that investigated the adequacy of pre-university Mathematics in preparing students for undergraduate Chemistry programmes, work of this kind has been undertaken in Physics. Work was undertaken by the Institute of Physics (Institute of Physics, 2011) to investigate anecdotal evidence that Physics and Mathematics A-levels are not preparing students sufficiently for undergraduate Physics and Engineering programmes, and that the Physics and Mathematics A-levels are not providing sufficient motivation for students to choose undergraduate Physics programmes. It was shown (Institute of Physics, 2011) that 79% of students felt that they were able to deal either very well or quite well with the mathematical content of their degree programme, although 55% of academics believed that students were not very or not at all well prepared to study this content successfully. Algebra, differentiation and logarithms were highlighted by staff and students as being relatively easy; while integration, identifying particular equations and techniques to deal with problems, and vectors and scalars were reported to be more challenging by both staff and students. In the same study (Institute of Physics, 2011), 37 of 40 (93%) of academics reported that their department/school offered support to students to help them deal with the mathematical content of their Physics degree. More than four in five (Institute of Physics, 2011) agreed that a lack of student proficiency in Mathematics affected their department's capacity to deliver an optimal programme of study in Physics.

A recent report published by the Royal Statistical Society (Porkess, 2013) describes the outcomes of research into how the ability to collect large amounts of data can be reflected in A-level syllabi in different subjects and the teaching opportunities that may become available. The report notes that Chemistry is intrinsically mathematical and so the introduction of more data related work is likely to be hard to achieve until other general Mathematics issues are resolved. It also suggests that these developments could contribute to an improvement in the general situation related to Mathematics.

As noted earlier, no specific mention is made of the mathematical skills required to underpin the Chemistry-related cognitive abilities and skills that are considered in the QAA subject benchmark statement for Chemistry (Quality Assurance Agency, 2007). In contrast, the equivalent subject benchmark statement for Physics, Astronomy and Astrophysics contains a number of statements regarding Mathematics. These include: "Students should learn that physics is a quantitative subject and appreciate the use and power of Mathematics for modelling the physical world and solving problems. Mathematics is an essential part of a physics degree." This statement would also be appropriate if directed at Chemistry instead of Physics. Another useful comparison is given by the QAA subject benchmark statement for Forensic Science (Quality Assurance Agency, 2012), which states explicitly:

> "In mathematics an appropriate basis would be sufficient knowledge and facility in functions, algebra and trigonometry to cover the mathematical aspects of the physics, chemistry and biology in the course. Appropriate statistics would be a working knowledge of the basis and application of statistical methods and probability for analysis of data and their uncertainties, including sampling methods. This should include an understanding and use of databases and frequency data, and use of the Bayesian approach for evaluation and interpretation of evidence."

and relates Mathematics directly to the Chemistry involved within the discipline. There is thus an opportunity for more explicit inclusion of mathematical requirements in the next revision of the QAA subject benchmark statement for Chemistry.

4.2 HEA STEM staff and student surveys in Chemistry

The students who responded to the HEA STEM student survey were fairly evenly split between the first, second and other years (Figure 1). All reported that they had studied Mathematics as part of their degree programme. (In what follows N is used to denote the number of responses to a particular question.)

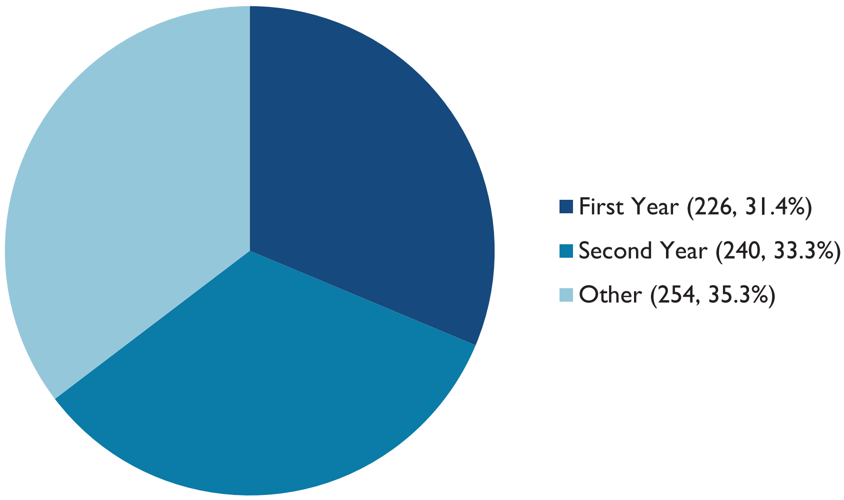

Figure 1: Distribution of student respondents to the HEA STEM student survey by year of study. (N=720).

Figure 2 shows the highest qualification in Mathematics that each possessed on entering university. This shows that a majority (544 of 721, 75%) were qualified to A-level standard or equivalent and 18 of 721 (2%) had a bare pass at GCSE or equivalent.

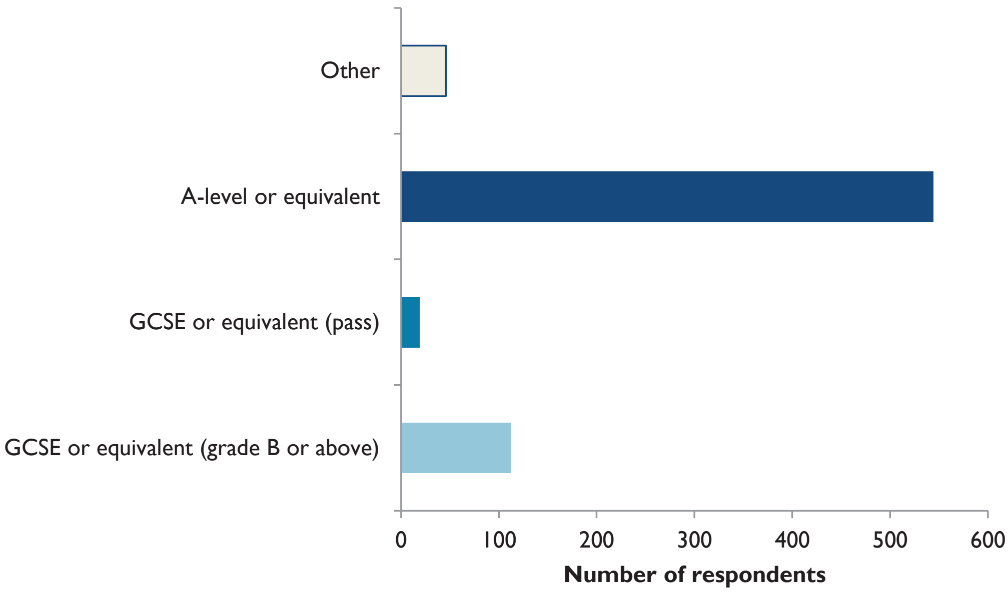

Figure 2: HEA STEM student survey: Highest Mathematical qualification of students. (N=721).

The high proportion of students entering with A-level Mathematics is in contrast to the entry requirements of individual departments. Figure 3 shows that only 8 of 39 (21%) of respondents in the staff survey report that this is a requirement. 29 of 39 (74%) report no additional requirement above institutional Mathematics requirements for entry.

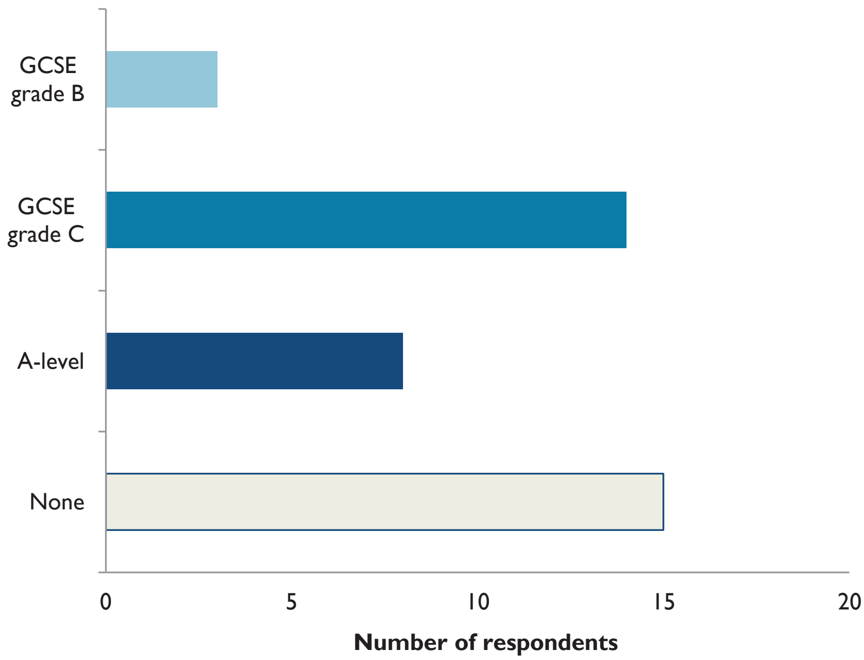

Figure 3: HEA STEM staff survey: Minimum Mathematics entrance requirement (N=39).

The vast majority of staff (33 of 39, 85%) responding to the HEA STEM staff survey regarded the mathematical content of the degrees that they teach as high or moderate, and a similar proportion agreed that Mathematics needed to be included in a Chemistry degree programme. Heads of department were more likely to disagree with this statement, which may be due to the fact that they are as likely to be specialists in inorganic or organic Chemistry while the other respondents, who teach mathematically focused modules, will predominantly be physical chemists who appreciate the importance of Mathematics in underpinning the degree.

Compulsory module(s) with a substantive component (50% or more) of Mathematics are run in years one and two, with about half the number run in year two as in year one. There is little evidence of such modules being run in later years but students report that support is available beyond year two. This support is either through university or department drop-in centres for Mathematics, online or written course help (Figure 5). About 10% (4 of 39) of respondents to the staff survey stated that no modules were run at all (these may have been in those that already required A-level Mathematics or its equivalent). This does not necessarily conflict with the earlier finding that all the student respondents had studied Mathematics as part of their degree programme. Of those modules run in year one, 64% (25 of 39) of respondents stated that modules run had a substantive Mathematics component, i.e. 50% or more Mathematics, with the remainder reporting that Mathematics was embedded within Chemistry modules. Of those modules run in year two, only 13% (5 of 39) of respondents stated that modules had a substantive Mathematics component whereas the rest reported that Mathematics was embedded in Chemistry modules. Virtually all respondents stated that where Mathematics content existed in later years, it was embedded within Chemistry modules.

Where modules are run, the topics most commonly taught are (in decreasing level of frequency): calculus, substitution into formulae, algebra and error analysis, interpreting plots, complex numbers, trigonometry, statistical distributions, vectors, matrices and probability (Figure 4). It is interesting to note that only substitution into formulae and algebra are universally taught. This contrasts with complex numbers, matrices and probability which are reported as not covered by more than 1 in 5 respondents. Topics are generally more likely to be taught than practised, and in turn more likely to be practised than assessed. This suggests that students are sometimes expected to have familiarity with a topic that they will meet, rather than being able to demonstrate proficiency. The more general topics are likely to be embedded in the degree programme even if not taught in a compulsory module.

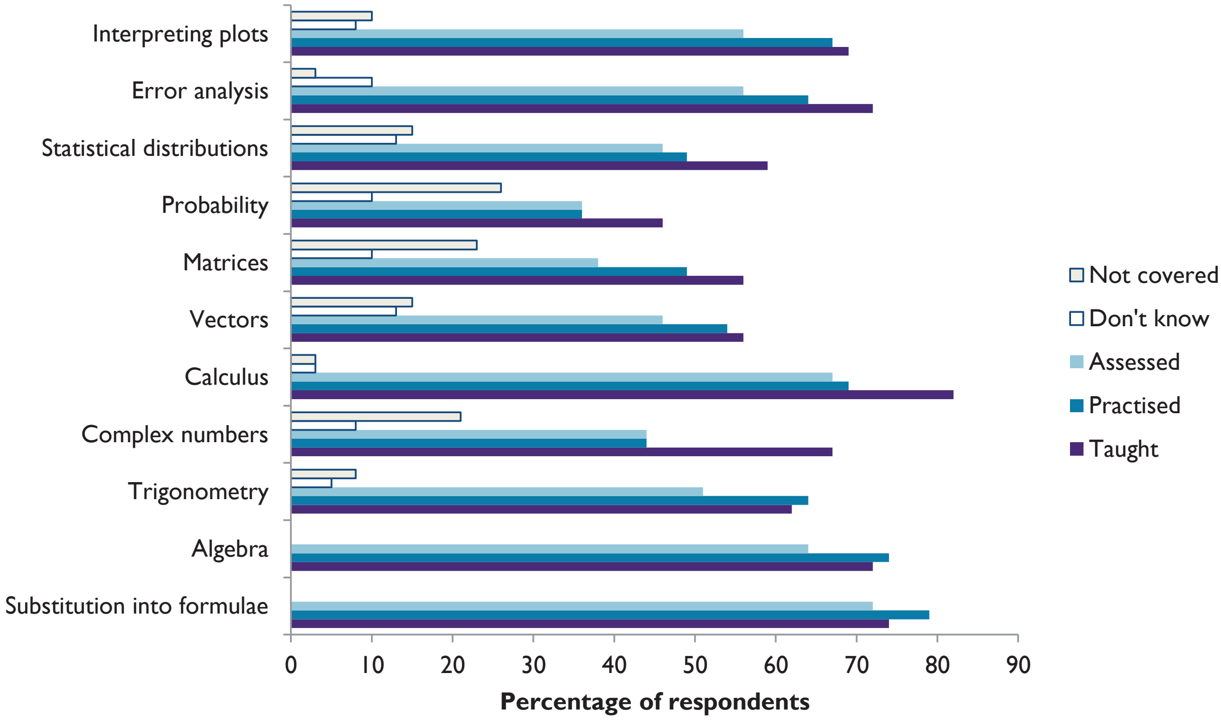

Figure 4: HEA STEM staff survey: Percentage of staff respondents reporting which mathematical topics are taught, practised and assessed (N=39).

In most Chemistry modules taught in years three and four supporting workshops where mathematical support is available are offered where appropriate. Some institutions also run Mathematics workshops where students can work through sheets of chemical Mathematics questions relevant to modules with academic support. 65% (467 of 721) of students and 82% (32 of 39) of staff surveyed reported that there was additional support provided in Mathematics, while 27% (197 of 721) of students did not know and 8% (57 of 721) of students and 18% (7 of 39) of staff said no additional support was available. The range of support reported by students is summarised in Figure 5 and its breadth appears to be similar to that reported in the social sciences (MacInnes 2009 and 2012). Staff were generally more aware of this support than were students, although a notable exception were drop-in services within the department. Many of these support mechanisms have been discussed by Marr and Grove (2010). In the HEA STEM student survey online resources were reported to be the most common, with supplementary workshops and drop-in services provide by institutions (more commonly) and departments close behind. However, of those students surveyed only 31% (146 of 467) made use of this additional support and of those about 97% found it useful. Such additional support was most commonly available in all years of the programme although a notable number of respondents (110 of 467) stated that this was only available in the first year. Two students reported that this additional support was available before the programme had actually started. Recently, Shallcross *et al.* (2011) ran summer schools in Mathematics for students who did not have A-level Mathematics and attended higher education institutions. It has been noted elsewhere (Institute of Physics, 2011) that students admit that they do not make enough use of the resources made available even when they are aware of them. It should therefore be possible to raise awareness of such resources and encourage their uptake.

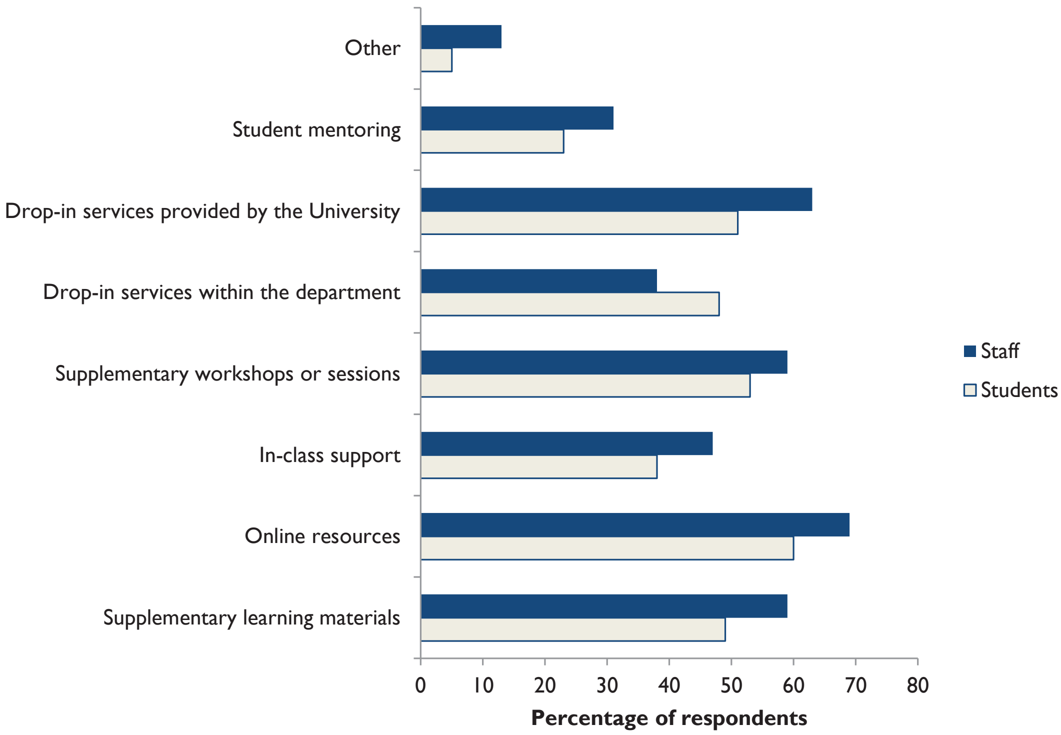

Figure 5: Forms of additional support made available to students needing extra assistance with their mathematical and/or statistical knowledge and/or skills (HEA STEM surveys, N=467 students, N=32 staff).

Based on the HEA STEM survey results from teaching staff (N=39), the main reasons that students struggle with Mathematics are, in decreasing order of importance (Figure 6): lack of confidence, lack of numeracy skills and Mathematics or Statistics anxiety. There were some interesting differences with the student survey (N=158) results (Figure 6) on the question about why students struggle with Mathematics, although students also place a lack of confidence as the most important factor. Fewer felt that failure to ask for help and a lack of practice was important. The proportion who identified the time elapsed since Mathematics was last studied was similar to that for staff and the fact that this was identified as important by both groups suggests that it may be an area worthy of attention. There was a mismatch in the responses from the two surveys in that no staff identified a lack of IT skills as a reason why students struggle with Mathematics while some (13 of 158) students believed this to be the case.

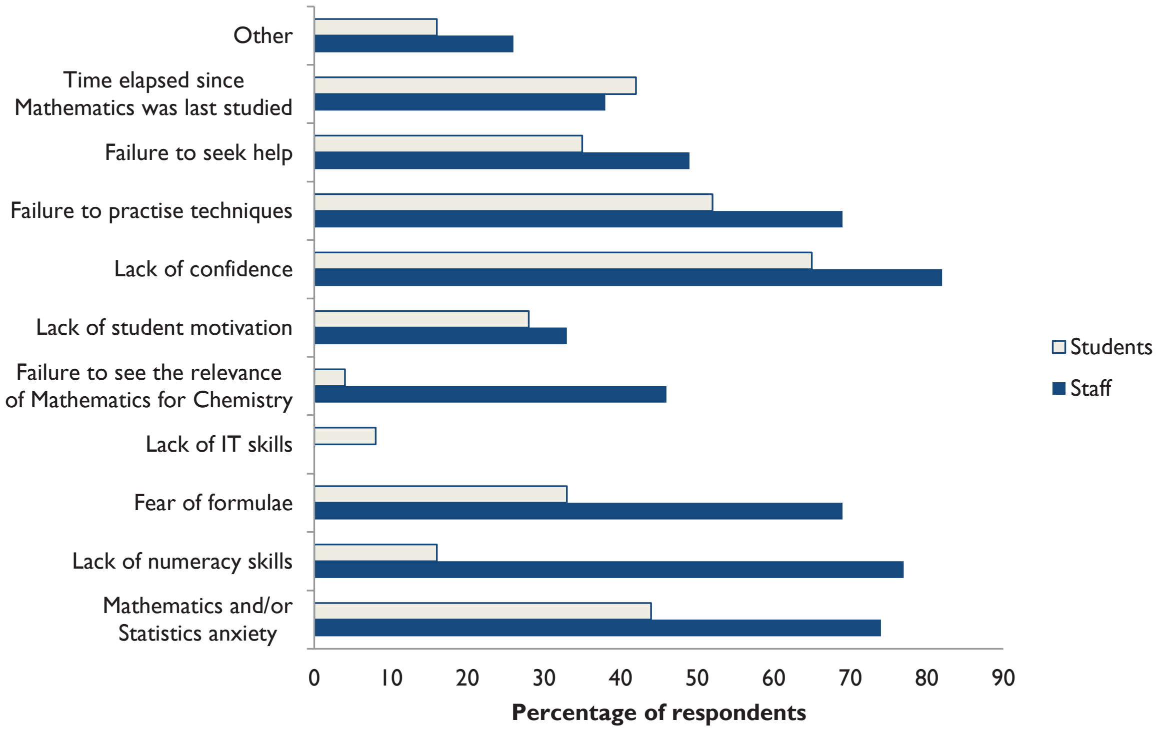

Figure 6: HEA STEM surveys: Staff (N=39) and student (N=158) perceptions of why students struggle with Mathematics.

An analysis of students' attitudes can be further divided into those that attend universities in Scotland (N=39) and those that attend universities in the rest of the UK (N=119). Although no information is available to determine whether students attending these universities are from Scotland or not there are some interesting differences, although caution must be exercised in their interpretation due to the difference in sample sizes. When asked the question "In your opinion, which of the following contribute to why you struggle with Mathematics?", higher scores were recorded in every category for students in the rest of the UK category (Figure 7). Most notably, many more students record that not doing any Mathematics at least one or two years before starting a degree contributes to their struggle with Mathematics. In the Scottish system students typically study five subjects at Higher level, so are more likely to continue to study Mathematics post-16. This fact could perhaps provide an explanation of this result. It is also notable that no students at Scottish universities reported issues with their IT skills unlike those from the rest of the UK. All of these elements have been identified (Childs and Sheehan, 2009) and stem in part from the introduction of new Mathematics at the same time as introducing new Chemistry. The problem is not confined to students entering undergraduate Chemistry programmes with GCSE grade C or equivalent as their highest Mathematics qualification. Those students with A-level Mathematics who tend to adopt algorithmic approaches to solving Mathematics problems struggle to translate their mathematical knowledge into chemical contexts (Scott, 2012). As previously discussed, approaches have been adopted to introduce students to the alternative approach involving intuitive reasoning.

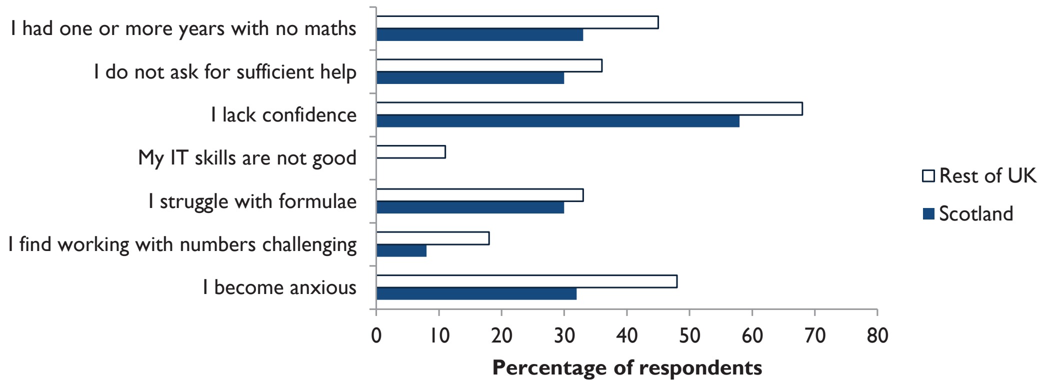

Figure 7: HEA STEM student survey: A comparison between student attitudes when asked the question "In your opinion, which of the following contribute to why you struggle with Mathematics?" (N=39 Scotland, 119 Rest of UK).

The HEA STEM staff survey indicated that students struggle to translate mathematical knowledge into the context of Chemistry (Figure 12). They also struggle to learn new mathematical concepts at the same time as new chemical ones, where Mathematics is taught in the context of Chemistry. Most respondents (31 of 39, 79%) reported that new mathematical concepts are contextualised so that their relevance to Chemistry is clear, although this does not necessarily require the introduction of new Chemistry.

Student responses to the question "Which of the following most accurately describes how you find Mathematics?" are shown in Figure 8. 26% (187 of 721) always or usually find Mathematics difficult when students with all levels of Mathematics qualifications are included. Considering only those students whose highest Mathematics qualification is GCSE grade C or equivalent, over half (67 of 116) always or usually find Mathematics difficult. This response is not surprising and shows that some students with A-level Mathematics will struggle. These results from students support the fact that 87% (34 of 39) of staff either agreed or strongly agreed with the statement that "there is wide variability in the numeracy and statistical skills of students on Chemistry degree programmes". Further evidence of this is provided by the student survey where 24% of students (176 of 721) report that they do not perform as well in assessments on Mathematics as in other areas of the degree, 41% (294 of 721) perform about the same and 35% (251 of 721) perform better.

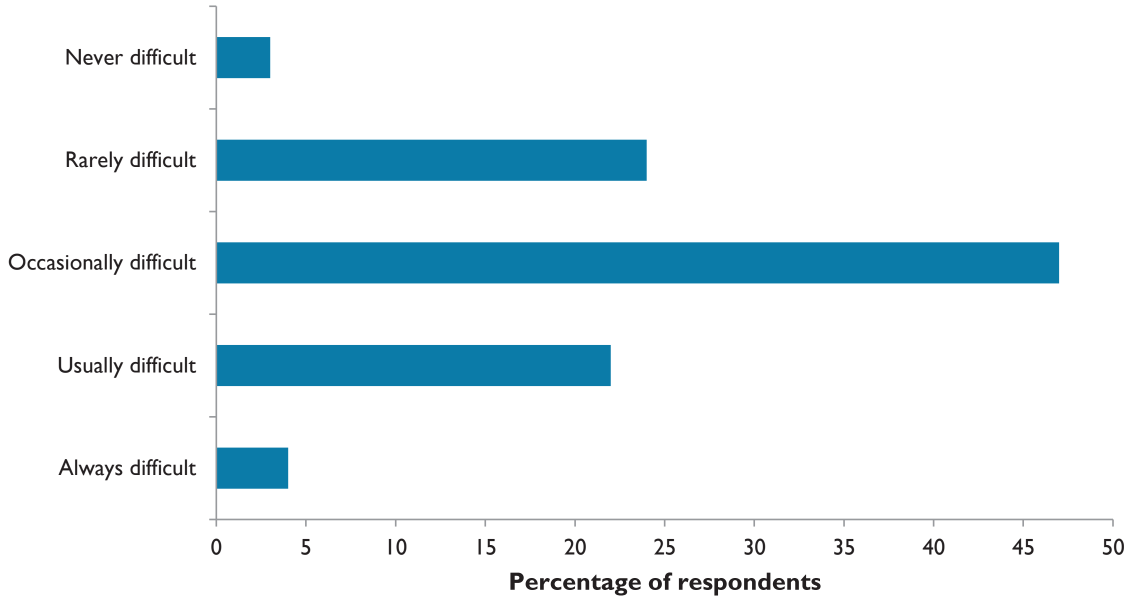

Figure 8: Responses to the question in the HEA STEM student survey "Which of the following most accurately describes how you find Mathematics?" (N=721).

These results suggest that the biggest problem for Chemistry degree programmes is dealing with the wide range of mathematical abilities of incoming students. Despite this, the HEA STEM staff survey results showed that only about a quarter of respondents (10 of 39, 26%) said that their programme divides students into different streams for Mathematics teaching. In several cases (4 of 10, 40%) streaming was determined by a diagnostic test which could be a written or online test, an introductory assignment or of a different type. Diagnostic tests were used to gauge skill levels, inform students about their knowledge and skills and to enable tutors to direct individual students to appropriate support. About 20% of students (147 of 721) reported that they were tested to determine their level of Mathematics, which is in broad agreement with the results from the smaller HEA STEM staff survey (12 of 39, 31%). The students reported the same types of test as did the staff with one student reporting that they had an oral test (Figure 9). No respondents reported more sophisticated uses of diagnostic testing such as using these to predict programme success rates (Legg *et al.*, 2001).

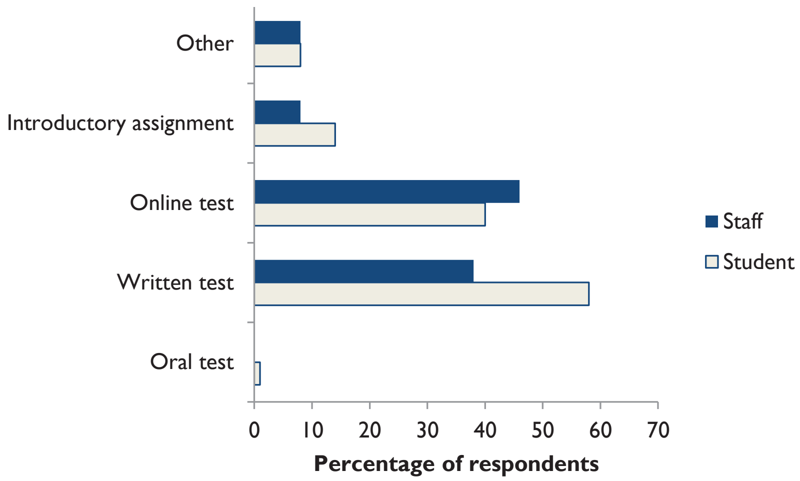

Figure 9: HEA STEM surveys: Forms of diagnostic testing used as reported by percentages of staff (N=13) and students (N=148).

77% (20 of 26) of respondents to the HEA STEM staff survey stated that a member of the Chemistry department taught the Mathematics modules, so the number of modules being taught by non-chemists is relatively low. A very high number (20 of 22, 91%) of staff reported having current or recent (last 5 years) experience of teaching Mathematics on the Chemistry degree programme. However, no respondent reported that any training specifically tailored to teaching Mathematics was provided. All were very confident or confident about their subject knowledge of the Mathematics they have been teaching. In 25% (1 of 4) of responses from heads of department, it was noted that postgraduates were used to assist the teaching of Mathematics. None of these had any training in Mathematics teaching. It is encouraging that the level of the staff member's expertise in Mathematics (22 of 26, 85%) and the currency of the staff member's experience of teaching Mathematics (17 of 26, 65%) were the most common reasons cited by all staff surveyed for allocating members of staff to Mathematics teaching. The full range of reasons is shown in Figure 10; it should be noted that respondents were able to select more than one reason.

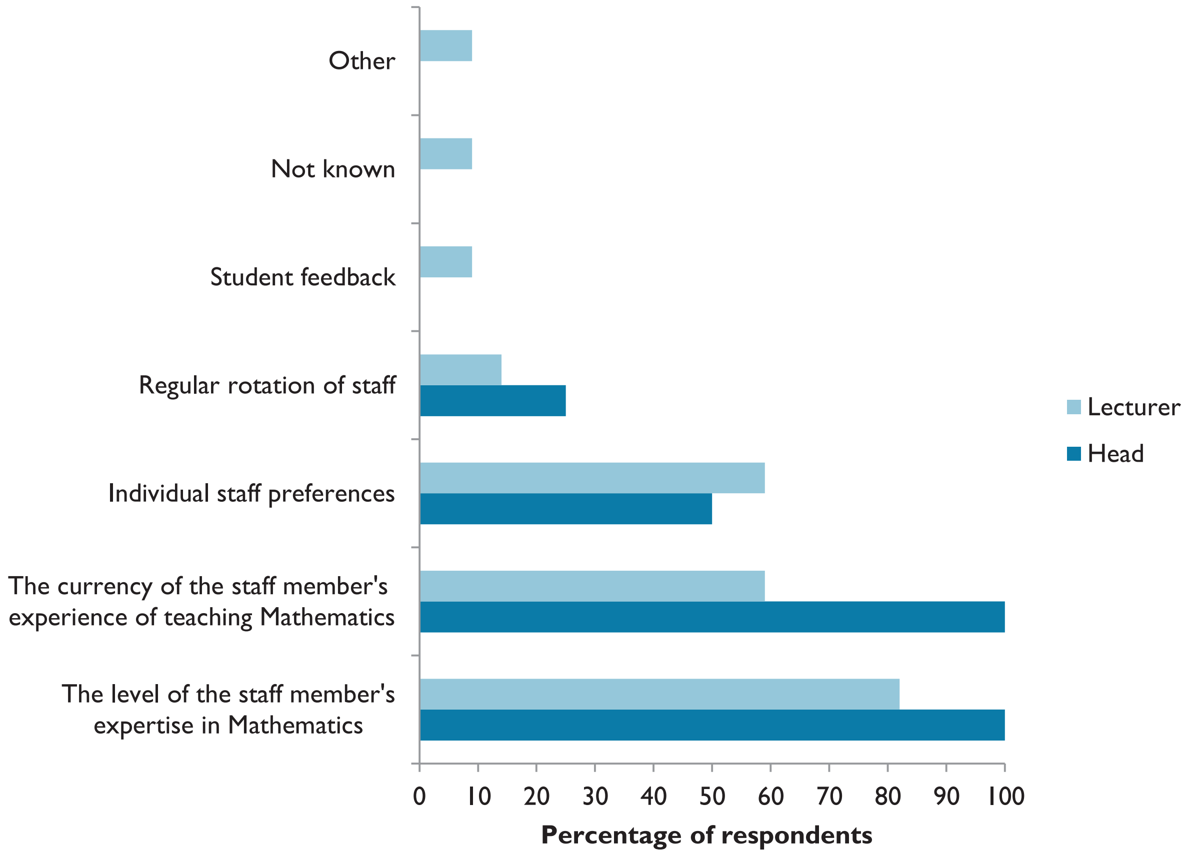

Figure 10: HEA STEM staff survey: Responses to the question "When decisions are being made about allocating staff to teach Mathematics components of modules what factors are taken into consideration?" by heads of department (N=4) and lecturing staff (N=22).

Based on the responses from students to questions concerning their expectations, (Figure 11), 91% (656 of 721) stated that they were aware that there was some Mathematics requirement in their degree programme before they started. The corresponding figure for those with GCSE grade C Mathematics or equivalent as their highest qualification was 88% (102 of 116). 94% (677 of 721) reported that they did see the relevance of the Mathematics they studied for other areas of the Chemistry degree. Although this is encouraging there are still 9% (65 of 721) who did not think there was any Mathematics requirement during a Chemistry degree.

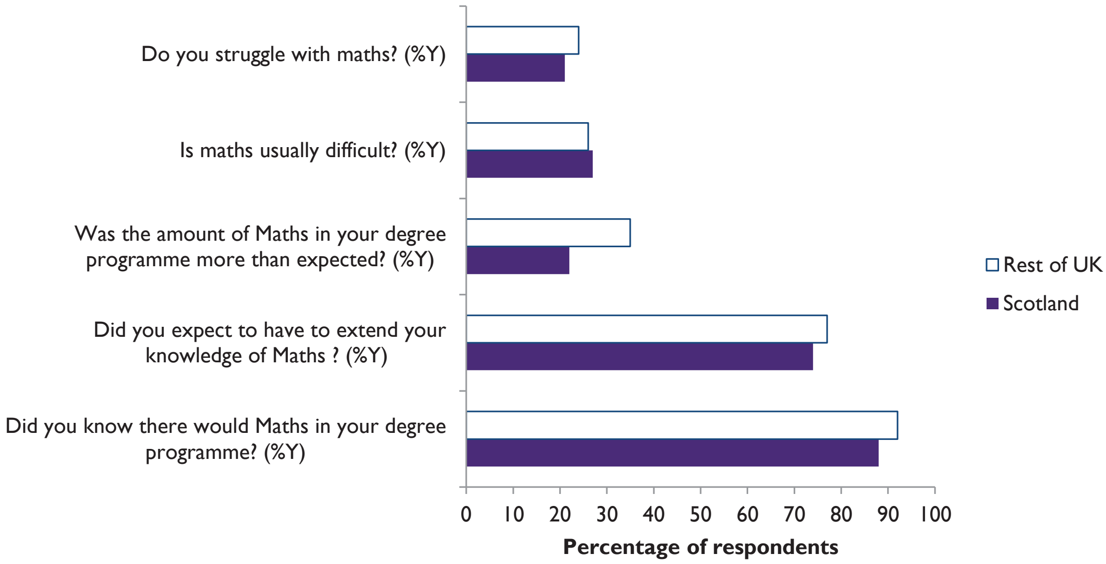

Figure 11: HEA STEM student survey: A Comparison between student responses (N=153 Scotland, 564 Rest of UK).

Interestingly, when asked whether they expected to have to extend their knowledge of Mathematics as part of their degree programme, over a quarter (26%, 186 of 721) said that they did not, and this was not biased towards those institutions asking for A-level Mathematics or its equivalent. Almost a third (32%, 234 of 721) felt that the programme had more Mathematics content in it than they expected, over half (55%, 399 of 721) felt that it was about what they expected and only the relatively small remainder (12%, 88 of 721) recorded that it was less than they expected. Scottish students (N=153) appear to have more realistic expectations than those from the rest of the UK (N=564). In the post-16 system in Scotland, students will study a range of up to five subjects at Higher level and it is possible that more students continue with some Mathematics at post-16 than elsewhere in the UK. For the subset of students across the UK surveyed with GCSE grade C Mathematics or its equivalent as their highest Mathematics qualification, 17% (20 of 116) thought they would not be extending their Mathematics knowledge. Therefore, there is a sizeable cohort of students who are not expecting the level of mathematical content that they encounter. On undertaking their degree programmes, 97% (699 of 721) said that they understood why quantitative methods were in their programme but fewer (73%, 526 of 721) believed that someone from the academic staff had explained why Mathematics is an important component.

It is interesting to contrast these responses with those from staff, over half of whom (56%, 22 of 39) disagreed with the statement that "students start their degree programme with realistic expectations about the amount of Mathematics and/or Statistics it will involve". A further third (12 of 39, 31%) had a neutral response to this statement. Nearly half (46%, 18 of 39) agreed that "Students understand why Mathematics is included in their degree programme". This is an area where improvement should be achievable with relatively little effort. The full set of responses to these questions is given in Figure 12. These have been grouped into three categories by combining agree/strongly agree and disagree/strongly disagree.

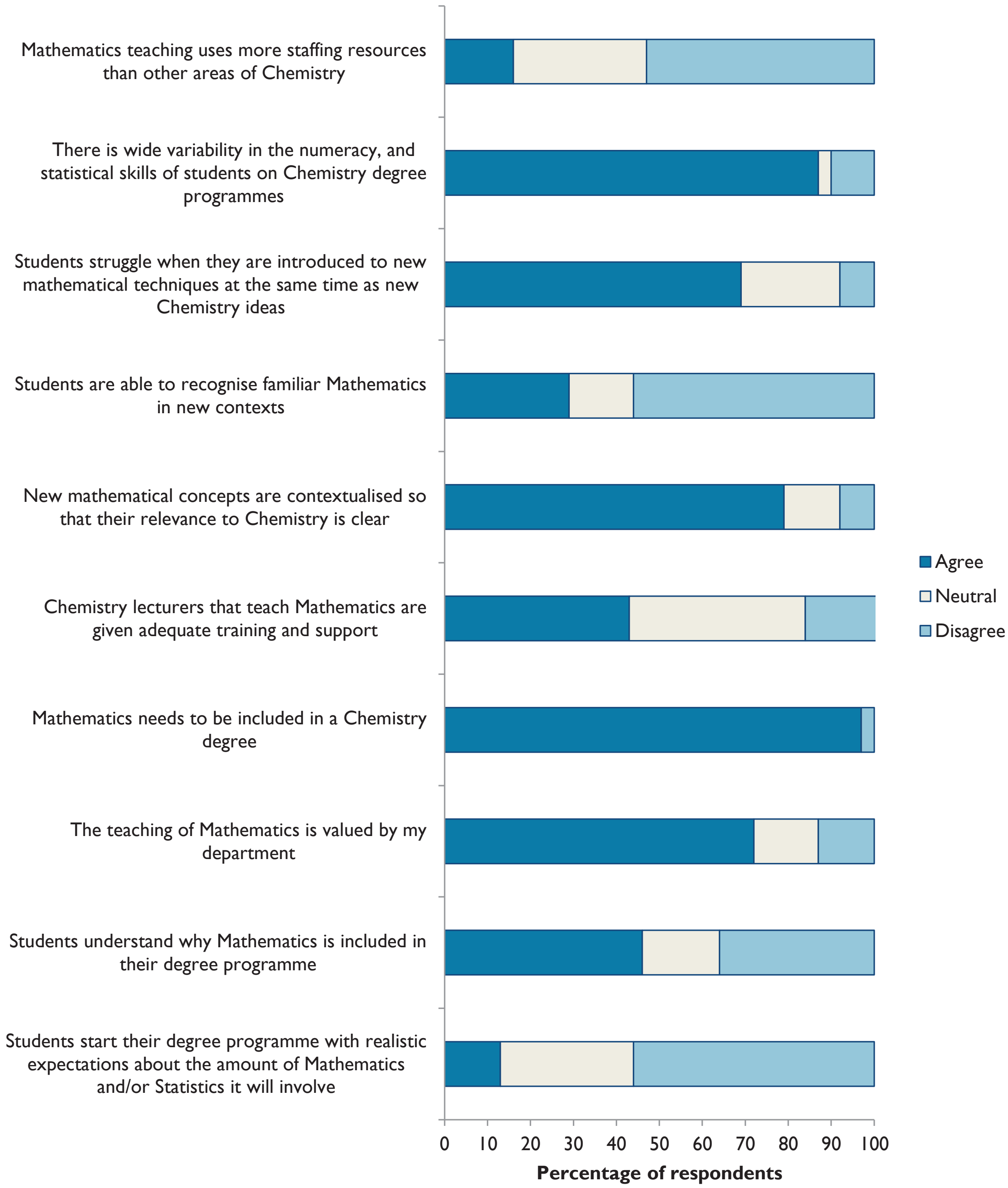

Figure 12: HEA STEM staff survey responses (N=39).

4.3 HEA STEM Tackling Transition event in Chemistry

The Tackling Transition event provided an opportunity for information to be gathered in a less structured format than the HEA STEM surveys, and for those interested to express their views and get involved. However, it is important to note that this event was attended by a small self-selected group (20 people in total) and therefore any conclusions need to be treated with caution as they may not be totally representative of the community as a whole.

A general conclusion from the discussion session was that there is insufficient opportunity for practitioners from the secondary and tertiary sectors and other stakeholders to meet and engage in dialogue. This was felt to be a much wider issue than just that of mathematical skills, and all of those who completed an anonymous feedback questionnaire distributed afterwards expressed an interest in attending similar events in the future.

There was a feeling among delegates that simply making A-level Mathematics or its equivalent an entry requirement for degree level Chemistry would only have limited benefit. There was much more support for the type of targeted support that is currently provided by universities, but there was also interest in a post-GCSE Mathematics qualification that was aimed at those wishing to study Chemistry or other science at university. It was felt that with government proposals (at the time of the event) for students to study some Mathematics up to age 18 there could be a possibility of shaping a new Mathematics qualification that provides a better preparation for a Chemistry degree. Delegates believed that this would provide the context for the Mathematics that was identified as being important in the staff survey and in the discussions held.

Few of the teachers of A-level Chemistry at the meeting believed GCSE grade C Mathematics or its equivalent to be sufficient for students who wish to take a Chemistry degree. They thought that the fact that this is the most common entry requirement implies that universities will provide appropriate support in Mathematics. Consequently they felt that there is therefore little incentive to encourage students to take A-level Mathematics, particularly as this is perceived to be a difficult A-level by students and as having a possible detrimental effect on the position of the school in league tables by senior school managers. Those present reported that within schools there is little communication between teaching colleagues in science and Mathematics as the relevant curricula are independent.

The university teachers present felt that the in-house modules in Mathematics were viewed as a necessary evil rather than something they were enthusiastic to teach. Anecdotal evidence was that such modules were given to new members of staff or more senior research-inactive staff to teach, a finding that was not supported by the results from the HEA STEM staff survey, which indicated a much closer match to staff expertise.

The wide availability of online and other resources identified in the HEA STEM staff and student surveys was supported in the discussions, as was the reticence of students to engage with these. It was suggested that this was due to a lack of confidence or a perception that Mathematics was not important. Although these factors were identified in the staff and student surveys the link between them and the lack of engagement was an interesting aspect of these discussions.

Delegates also felt that a clear statement on the mathematical skills required by incoming students on Chemistry degree programmes would be useful. Further discussion would be required to identify where such information might be best placed.

5 Conclusions

It is clear from a review of the literature that there is perceived to be a "Mathematics problem" in Chemistry. In the HEA STEM surveys of staff and students, lack of confidence was the most commonly cited reason for Chemistry students struggling with Mathematics, and the finding is mentioned frequently in the literature too. Formal taught modules in Mathematics for chemists are most common in year one, and a majority of such Mathematics for chemists modules are taught by a member of the Chemistry department. Despite anecdotal evidence to the contrary, the HEA STEM survey results suggest that staff are allocated to teach these modules on the basis of their suitability and all were confident of being able to deliver them. However, only 73% (526 of 721) of student respondents claimed that the relevance of Mathematics to Chemistry had been explained to them. Subsequently Mathematics is embedded within Chemistry modules. Additional support in years after year one is more likely to be provided by other means within a department or in the wider university. Results from the HEA STEM surveys, together with the Tackling Transition event, indicate that departments where Chemistry degree programmes are taught have robust support mechanisms in place to support their students with Mathematics. However, some students (27%, 197 of 721) are not aware of this and only a minority of those who were aware made use of it. The overwhelming majority of these students found the support useful, so it would be sensible to raise awareness of such resources and encourage their use.

In the HEA STEM staff survey 87% (34 of 39) of respondents believed that there is a wide range in the mathematical skills of students, a view supported by the finding in the HEA STEM student survey that 26% (187 of 721) of students found Mathematics always or usually difficult. Staff do not believe that any students struggle due to a lack of IT skills, although an appreciable minority of students (8%, 13 of 158) themselves believe this to be the case. The wide range of knowledge and skills arises partly from the relatively modest Mathematics entrance requirements for degree programmes in Chemistry. Only 21% (8 of 39) of respondents in the staff survey reported that A-level Mathematics or equivalent is a requirement. 74% (29 of 39) have no additional requirement above institutional Mathematics requirements for entry. The HEA STEM student survey indicated however that three quarters of the students were qualified to A-level standard or equivalent in Mathematics. Students with A-level Mathematics often do have an advantage over those who do not. However, about a quarter of the total cohort of students, still find the Mathematics within their Chemistry degrees to be difficult. Considering only those students whose highest Mathematics qualification is GCSE grade C or equivalent, over half (67 of 116) always or usually find Mathematics difficult.

While delegates at the HEA STEM Tackling Transition event agreed that GCSE grade C Mathematics provided an insufficient basis for a study of degree level Chemistry, there was a feeling that simply making A-level Mathematics or its equivalent an entry requirement for degree level Chemistry would have only limited benefit. There was much more support for the type of targeted support that is currently provided by universities, but there was also interest in a post-GCSE Mathematics qualification that was aimed at those wishing to study Chemistry or other science at university. It was felt that with government proposals (at the time of the event) for students to study some Mathematics up to age 18 there could be a possibility of shaping a new Mathematics qualification that provides a better preparation for a Chemistry degree. Delegates believed that this would provide the context for the Mathematics that was identified as being important in the staff survey and in the discussions held. This development could provide a window of opportunity for universities to insist upon higher level entry requirements to Chemistry degree programmes. The proposed post-16 qualification in Mathematics could also prove to be of benefit in addressing an issue highlighted by some students (42%, 67 of 158) who believe that they struggle with the mathematical aspects of their Chemistry degree programme owing to the time elapsed since they studied Mathematics (one or two years). Fewer students in Scotland, where the gap in study is smaller, believe this to be the case. Another way to address the time elapsed with no Mathematics study, for those students who have not taken AS or A-level Mathematics (or equivalent), is to encourage students to take advantage of other opportunities such as summer schools prior to entering university.

Diagnostic testing of students' mathematical skills on entry to university is implemented in about a third of degree programmes in Chemistry, with just 20% (147 of 721) of student respondents reporting that they had undergone such a test. The results of diagnostic testing can be used in a range of ways, and it would be valuable for degree programmes without diagnostic testing to introduce it and for all programmes to review their use of the results.

Students' expectations are an area where improvement should be achievable, by improved signalling from those in the higher education sector. In the HEA STEM staff survey, a majority of staff (22 of 39) believed that students were unaware of the extent of Mathematics required to undertake a degree in Chemistry, though only a minority of students (65 of 721) said that they were unaware of the extent of the Mathematics required to undertake a degree in Chemistry. In addition 32% (234 of 721) of students had found more Mathematics than expected in the degree programme.

Despite the perceived need for mathematical skills in Chemistry degree programmes, neither the relevant QAA subject benchmark statement nor the Royal Society of Chemistry accreditation documentation addresses this requirement in any detail. Mathematical skills are grouped under the requirements to develop generic and transferable skills. The next revisions of these documents should include more explicit mathematical requirements.

Finally, a general conclusion from the discussion session at the HEA STEM Tackling Transition event was that there is insufficient opportunity for stakeholders and practitioners from the secondary and tertiary sectors to meet and discuss relevant issues. These were felt to be much wider than just the issue of mathematical skills, and all of those who completed an anonymous feedback questionnaire distributed afterwards expressed an interest in attending similar events in the future.

6 References

Andrews, M. and Andrews, L. (1979) First year chemistry grades and SAT math scores. *Journal of Chemical Education.* **56**(3), 231–234.

Becker, N. and Towns, M. (2012) Students' understanding of mathematical expressions in physical chemistry contexts: An analysis using Sherin's symbolic forms. *Chemistry Education Research and Practice.* **13**, 209-220.

Childs, P.E. and Sheehan, M. (2009) What's difficult about Chemistry? An Irish perspective. *Chemistry Education Research and Practice.* **10**, 204-210.

Clifton, R., Baldwin, W.G., and Wei, Y. (2012) Course structure, engagement, and the achievement of students in first year Chemistry. *Chemistry Education Research and Practice.* **13**, 47-52.

Cockett, M. and Doggett, G. (2012) *Maths for chemists.* Cambridge: RSC Publishing.

Engineering Council (2000) Measuring the mathematics problem [online]. Available from: http://www.engc.org.uk/ecukdocuments/internet/document%20library/Measuring%20the%20Mathematic%20Problems.pdf [July 2013].

Hanson, S. and Overton, T. (2010) Skills required by new chemistry graduates and their development in degree programmes. York: Higher Education Academy.

Institute of Physics (2011) Mind the gap. Mathematics and the transition from A-levels to physics and engineering degrees [online]. Institute of Physics. Available from: https://www.iop.org/publications/iop/2011/file_51933.pdf [July 2013].

Legg, J.C., Greenbowe, T.J. and Legg, M.J. (2001) Analysis of success in general chemistry based on diagnostic testing using logistic regression. *Journal of Chemical Education.* **78**, 1117.

Leopold, D.G. and Edgar, B. (2008) Degree of mathematical fluency and success in second-semester introductory chemistry. *Journal of Chemical Education.* **85**, 724-731.

Loehr, J.F., Almarode, J.T., Tai, R.H. and Philip, M. (2012) High school and college biology: a multi-level model of the effects of high school courses on introductory course performance. *Journal of Biological Education.* **46**, 165-172.

MacInnes, J. (2009) Proposals to support and improve the teaching of quantitative research methods at undergraduate level in the UK [online]. Available from: http://www.esrc.ac.uk/_images/undergraduate_quantitative_research_methods_tcm8-2722.pdf [July 2013].

MacInnes, J. (2012) Quantitative methods teaching in UK higher education: The state of the field and how it might be improved [online]. Available from: http://www.heacademy.ac.uk/assets/documents/events/SS_assets/Blog/MacInnes_fullpaper1.pdf [July 2013].

Madden, S.P., Jones, L.L. and Rahm, J. (2011) The role of multiple representations in the understanding of ideal gas problems. *Chemistry Education Research and Practice.* **12**, 283-293.

Marr, C.M. and Grove, M.J. (2010) Responding to the mathematics problem: The implementation of institutional support mechanisms [online]. Available from: http://www.heacademy.ac.uk/assets/documents/subjects/msor/responding_to_the_maths_problem.pdf [July 2013].

Naah, B.M. and Slanger, M.J. (2012) Student misconceptions in writing balanced equations for dissolving ionic compounds in water. *Chemistry Education Research and Practice.* **13**, 186-194.

Ozsogomonyan, A. and Loftus, D. (1979) Predictors of general chemistry grades. *Journal of Chemical Education.* **56**, 173-175.

Pickering, M.J. (1975) Helping high-risk freshman chemists. *Journal of Chemical Education.* **52**, 512-514.

Porkess, R. (2013) A World Full of Data. Statistics opportunities across A-level subjects [online]. London: Royal Statistical Society. Available from: https://www.rss.org.uk/uploadedfiles/userfiles/files/A-world-full-of-data.pdf [February 2014].

Potgieter, M., Ackermann, M. and Fletcher, L. (2010) Inaccuracy of self evaluation as additional variable for prediction of students at risk of failing first year chemistry. *Chemistry Education Research and Practice.* **11**, 17-24.

Potgieter, M. and Davidowitz, B. (2011) Preparedness for tertiary chemistry: multiple applications of the Chemistry Competence Test for diagnostic and prediction purposes. *Chemistry Education Research and Practice.* **12**, 193-204.

Quality Assurance Agency (2007) Chemistry benchmark statement [online]. Available from: http://www.qaa.ac.uk/en/Publications/Documents/Subject-benchmark-statement-Chemistry-2007.pdf [July 2014].

Quality Assurance Agency (2012) Subject benchmark statement: Forensic science [online]. Available from: http://www.qaa.ac.uk/en/Publications/Documents/Subject-benchmark-statement-forensic-science.pdf [July 2014].

Regan, À, Childs, P. and Hayes, S. (2011) The use of an intervention programme to improve undergraduate students' chemical knowledge and address their misconceptions. *Chemistry Education Research and Practice.* **12**, 219-227.

Royal Society of Chemistry (1996) Mathematics in Chemistry Degree Courses.

Royal Society of Chemistry (2009a) Royal Society of Chemistry response to *Towards level 3 mathematics in 2016 – A paper to provoke discussion* by the Advisory Committee on Mathematics Education [online]. Available from: http://www.rsc.org/images/ACMERSCResponse_tcm18-170564.pdf [December 2012].

Royal Society of Chemistry (2009b) Discover maths for chemists [online]. Available from: http://discovermaths.rsc.org/ [December 2012].

Royal Society of Chemistry (2012) RSC Accreditation of degree programmes [online]. Available from: http://www.rsc.org/images/Accreditation%20Criteria%20January%202012_tcm18-151306.pdf [July 2013].

Royal Society of Chemistry and the Higher Education Academy (2009) Maths Resource Database [online]. Available from: http://www.heacademy.ac.uk/assets/documents/subjects/ps/maths_resources_feb09.pdf [October 2013].

Scott, F.J. (2012) Is mathematics to blame? An investigation into high school students' difficulty in performing calculations in chemistry. *Chemistry Education Research and Practice.* **13**, 330-336.

SCORE (2012a) Mathematics within A-level science 2010 examinations research report [online]. Available from: http://www.score-education.org/media/10036/full%20maths.pdf [December 2012].

SCORE (2012b) Mathematics within A-level science 2010 examinations policy report [online]. Available from: http://www.score-education.org/media/10033/score%20maths%20in%20science%20summary%20report.pdf [December 2012].

Seery, M.K. (2009) The role of prior knowledge and student aptitude in undergraduate performance in chemistry: A correlation-prediction study. *Chemistry Education Research and Practice.* **10**, 227-232.

Shallcross, D.E. (2006) Seeing what to do: Moving between abstract mathematical techniques and applied problem solving, case studies from chemistry students. *M.Ed. Dissertation*, Bristol University.

Shallcross, D.E., and Walton, G. (2007) What's in a grade? The real meaning of mathematics grades at GCSE and A level. *New Directions in the Teaching of Physical Sciences*. **3**, 73-76.

Shallcross, D.E., Allan, N.L. Shallcross, K.L., Croker, S.J., Smith, D.M., May, P.W., Price, G.J., and Harrison, T.G. (2011), Solving the maths problem in Chemistry: the impact of a pre-university maths summer school on year 1 and year 2 Physical and Theoretical Chemistry. *New Directions in the Teaching of Physical Sciences.* **7**, 58-62.

Sutherland, R. and Dewhurst, H. (1999) Mathematics education framework for progression from 16-19 to HE. Bristol: University of Bristol Graduate School of Education.

Tai, R.H., Sadler, P.M. and Loehr, J.F. (2005) Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching.* **42**, 987-1012.

Tai, R.H., and Sadler, P.M. (2007) High school chemistry instructional practices and their association with college chemistry grades. *Journal of Chemical Education.* **84**, 1040-1046.

Wagner, E.P., Sasser, H. and DiBiase, W.J. (2002) Predicting students at risk in general chemistry using pre-semester assessments and demographic information. *Journal of Chemical Education.* **79**, 749-755.

Yates, P.C. (2002) Is the mathematics problem recognized by the chemical industry? *University Chemical Education.* **6**, 17-21.

Yates, P.C. (2012) New strategies for teaching maths to chemistry students. *Analytical and Bioanalytical Chemistry.* **404**, 2787-2792.

Yates, P.C. (2013) Fractions. *Education in Chemistry.* **50**, 14-15.

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