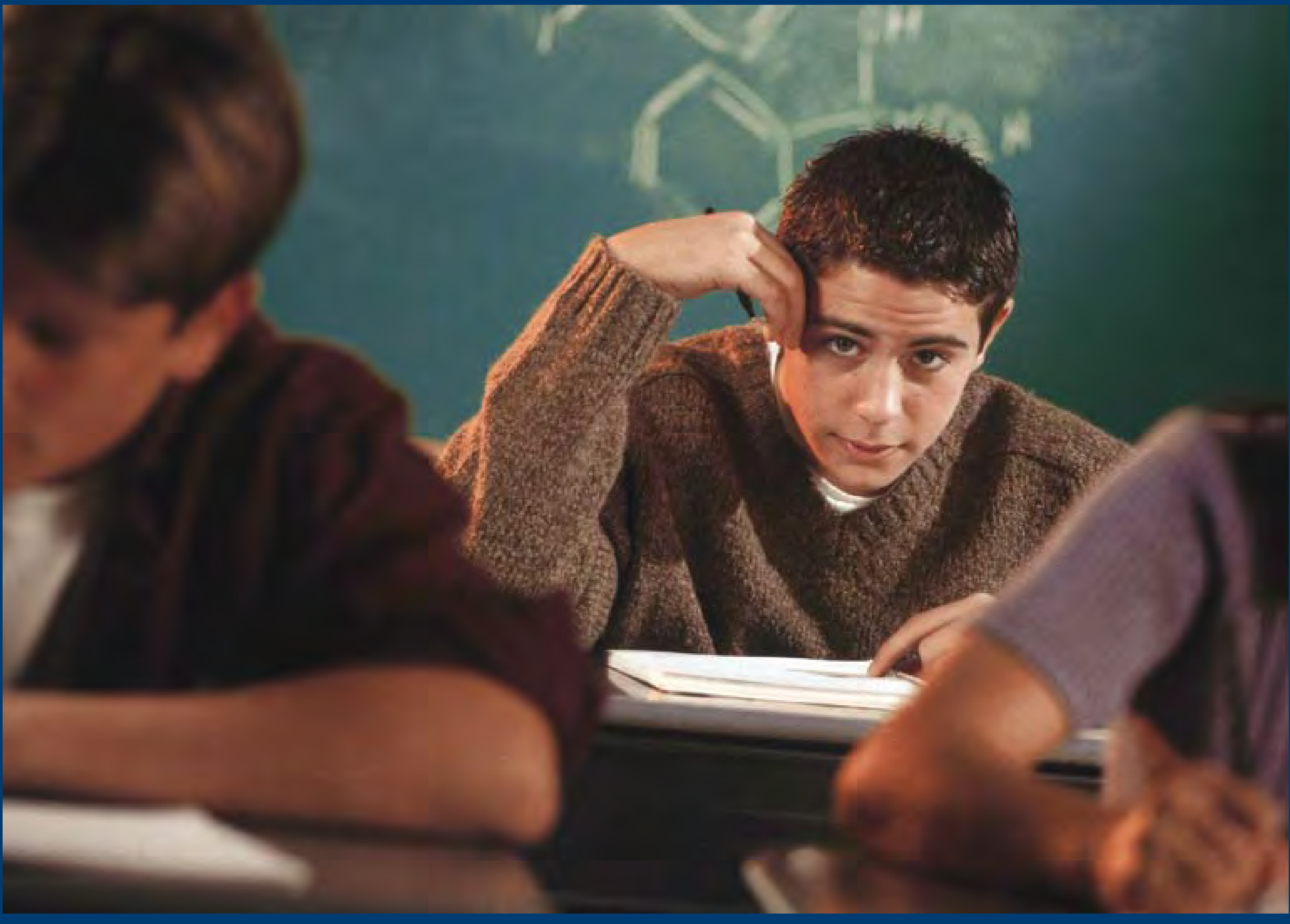
The Five-Decade Challenge

A wake-up call for UK science education?
November 2008



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Foreword

During the coming decades, chemistry will be key in addressing global issues relating to energy, food, water, the environment, health and overall sustainability. If the subject is to retain its strong scientific research base in the UK, and benefit from innovation throughout the industrial and other commercial sectors, it is essential that this country's education system can provide both science graduates and a broader technically-literate society with the relevant knowledge and skills.

Industrialists and senior academics are placing increasing priority on problem-solving and strong mathematical abilities, rather than the mere recalling of facts or simplistic analysis within well-defined boundaries of experience.[1] This follows from the extraordinary and rapid proliferation of information globally, which means that success goes to those who can most readily analyse and deliver in unfamiliar, complex or uncertain business and technological environments.[2]

Over the last five decades, the national examinations set for 16 year-olds in science in England, Wales and Northern Ireland have changed markedly, from the General Certificate of Education (GCE) Ordinary Level (O-level) system of the 1960s, 1970s and 1980s, which was set for more able pupils and ran in parallel to the Certificate of Secondary Education (CSE), to the broadly based framework of the General Certificate of Secondary Education (GCSE) through the 1990s and this decade.

Within this arrangement, there have been many changes over time to the criteria set by the Qualifications and Curriculum Authority (QCA) and specifications (syllabuses) derived by five competing Awarding Bodies that manage the assessment process. According to published examination results, the performance of 16-years olds has improved without interruption for twenty successive years. This has inevitably caused many to question the standards of the examinations,[3] although such criticism has often been based largely on anecdotal rather than quantitative evidence of the trends.

The Royal Society of Chemistry (RSC) decided this year to conduct a unique chemistry competition which would test 16-year olds, drawing on a selection of questions mainly with a mathematical or analytical basis from O-level and GCSE examinations set in the five decades since the 1960s. This quantitatively tested the way in which students are able to manage chemistry questions from earlier years, and enabled us to analyse the response to different styles and complexity of questions.

In conducting the 40-question two-hour test in the form of a competition, the RSC invited schools in the UK to nominate their most promising young scientists to take part, offering financial prizes to the top-ten pupils (£1,000 to the individual winner) and their schools. About 9% of schools responded and registered to participate across the UK, and the competition was set online to allow pupils in schools to sit the test from their own classrooms simultaneously on Friday, 27th June 2008. It is intended that the results from this innovative exercise, despite the limitations of its conditions, should positively influence educational policy over the forthcoming years.

Richard A. Pike

Richard Pike - Chief Executive
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1 *Sustaining the Skills Pipeline*, The Association of British Pharmaceuticals Industry (November 2005)
2 *Research and Development: Going Global*, OECD (2008) http://www.oecd.org/dataoecd/30/52/41090260.pdf
3 *Summary of Research on Changes in Educational Standards in the UK*, Coe, R. and Tymms, P. (2008) in M. Harris, *Education Briefing Book 2008: IoD Policy Paper*. London: Institute of Directors, August 2008

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About the RSC

Since 1841, the RSC has been the leading society and professional body for chemical scientists and we are committed to ensuring that an enthusiastic, innovative and thriving scientific community is in place to face the future. The RSC has a global membership of over 44,000 and is actively involved in the spheres of education, qualifications and professional conduct. It runs conferences and meetings for chemical scientists, industrialists and policy makers at both national and local level. It is a major publisher of scientific books and journals, the majority of which are held in the RSC Library and Information Centre. In all its work, the RSC is objective and impartial, and is recognised throughout the world as an authoritative voice of the chemical sciences.

Conclusions

The conclusions and recommendations below are made on the basis of a purposely-designed chemistry competition for 16 year olds, set against the backdrop of wider challenges that the UK science base faces. More than 1,300 self-selecting higher-ability students took part in this exercise. Questions used in the competition were drawn primarily from the numerical and analytical components of O-level and GCSE examinations from the last five decades.

1. **Many teachers want to take the opportunity to stretch the abilities of their most promising pupils, and these pupils are eager to take up this challenge.** The large number of entries to this competition indicates that teachers strongly support their pupils proving their abilities outside of GCSE examinations. We congratulate the pupils and teachers who took the time to participate in this competition, despite most candidates having recently completed their GCSE examinations.

2. **Performance against each decade showed a remarkably steady step-wise progression, with the average scored for the 1960s questions being 15%, rising to 35% for the current 2000s decade.** Changes to the syllabus and to the language used in examinations since the 1960s may partially explain this progression, but are unlikely to provide a complete explanation. There was a significant increase in average marks between the 1980s and 1990s, corresponding to the transition from the O-level to the GCSE system, which was first examined in 1988. The increase between the 1990s and 2000s was small, suggesting that the level of difficulty of the numerical or analytical component of GCSEs has remained unchanged over the twenty years since this transition, although such questions form a small proportion of typical papers.

3. **There is an urgent need to enhance the level of problem-solving and quantitative skills of 16-year olds in the UK.** The average mark in this largely quantitative test was 25%; some students scored no marks at all. However the distribution of marks was skewed and there were also some outstanding performances; the highest mark was 94%.

4. **Questions or their components requiring a single-step mathematical operation were answered most successfully, followed by questions requiring no mathematics (typically recall or logic). Those needing multiple mathematical steps, without prompting, were answered least well.** As few as one-tenth of the marks of more recent papers are allocated to numerically-based questions and often have prompting to guide the student. Correct steps following errors in multi step questions were not considered in the marking scheme for this competition.

5. **Only limited skills of applying mathematics to chemistry problems were evident, with questions requiring even very simple manipulation of numbers posing difficulties for many participants.** Determining the relative formula mass of magnesium chloride, given the chemical formula and relative atomic masses of magnesium and chlorine (from the 1990s), was answered correctly by only 56% of participants. Calculating the percentage mass of phosphorus in calcium phosphate, again with the formula and all relative atomic masses given (1960s), was answered correctly by 52%.

6. **Some more complex mathematical questions from earlier decades are no-longer taught at this level, and related topics, definitions and formulae were unfamiliar to most participants.** As expected, less than 1% of participants were able to answer a question on enthalpy and bond energies between pairs of atoms within the benzene molecule.

7. **Students from independent schools (25% of entrants) performed significantly better than those from the state sector (75% of entrants). Boys overall were more successful than girls, particularly in answering those questions regarded as more difficult mathematically.** Independent schools are more likely to teach science as three separate subjects (physics, chemistry and biology), and are understood to have a higher proportion of specialist science teachers. The gender difference in this competition is unusual; in GCSE chemistry on average girls attain similar, if not slightly higher grades and typical gender differences in GCSE science and mathematics are comparatively low.[4]

8. **The competition results indicate that the current educational system fails to recognise the most exceptional students with wider knowledge of the subject and the ability to tackle science-based problems.** The distribution of the results from this examination demonstrated the exceptional ability of some pupils; however, despite many teachers indicating they nominated A/A* students, most did not score well in this competition. In the 2008 GCSE examinations 77,000 took chemistry as a separate subject and over 52% achieved the top grades of A* or A.

[4] *Gender and Education: the evidence on pupils in England* (2007), Department for education and skills

Recommendations for School Science in England, Wales and Northern Ireland

Education inspectorates (Ofsted, Estyn and Eti) should:

1. **Review and improve the assessment of science and mathematics teaching in schools, in light of the outcomes of this competition.** The continuing professional development (CPD) should also be enhanced for chemistry teachers, including those for whom chemistry is not their degree specialism.

Curriculum authorities should:

2. **Improve the assessment system to better meet the future needs of the country. They should obtain national agreement over what pupils, at various ages, should know and be able to do in chemistry.** This should draw upon as broad an evidence base as possible from experienced representatives in industry, universities, educationalists, government and the wider business sectors, including benchmarking science education standards against those of other nations.

3. **Amend the chemistry curriculum taught in schools, and assessment procedures, to place a greater emphasis on the quantitative aspects of the subject.** This should strike a better balance between the broad nature of GCSEs and the reinforcement of multi-step problem-solving, incorporating associated mathematics, logic and lateral thinking, as a much more significant component of chemistry examinations, so that any deficiencies in the secondary education sector are not passed on for remedying within the tertiary sector (see Section 3). Chemistry questions should have a significant quantitative component to check students' understanding of the relationship between fundamental parameters, and an appreciation of numerical scale of phenomena.

4. **Support educators to improve coherence between the mathematics and science taught in schools so that science teachers do not have to teach fundamental numerical techniques in order to progress science lessons.** Coordination of subjects in the Programme of Study in the National Curriculum will help to ensure that well-timed mathematics lessons prepare students for the techniques that will be needed in science, and science lessons will, in turn, reinforce the mathematics syllabus later in the course. This will also promote the relevance of mathematics to broader disciplines. Relevant training and resources should be made available where appropriate.

5. **Introduce a grading system for examinations (and a new paper where necessary) that differentiates performance more meaningfully.** This will meet the needs of students, schools, universities, employers and the nation's longer-term requirements. The introduction of any new grades, such as the new A* grade, must be done in way that maintains standards and only recognises excellence where this exists.

Governments should:

6. **Initiate a significant increase in the number of appropriately qualified teachers entering the profession.** This will ensure that any amended curriculum, and a more rigorous assessment process, can be delivered nationally to meet the urgent needs of the country.

7. **Improve science facilities in UK schools so that they all meet a good standard.** There is strong evidence that good school laboratories can provide an environment which facilitates inspirational teaching and practical experimentation, ensuring that students have a good grasp of physical quantities and concepts beyond mere theory.

1. Methodology

Letters were sent to all UK schools, inviting them to nominate and register their most promising students to sit the online examination on 27th June 2008. This date was chosen as it was immediately after the GCSE examination period, to maximise availability of students who would, by then, have revised for and completed their school examinations.

Nevertheless, this was the last day of term for many Scottish and some independent schools, which reduced the number of participants from these schools who were able to take part.

Prize money was offered to the ten highest scoring entries, and an identical sum to their schools, to encourage wider participation. The top individual prize was set at £1,000, with those ranked 2nd to 10th each awarded £500.

Chemistry O-level and GCSE questions were selected from a number of examination boards from England, Wales and Northern Ireland drawing on the decades 1960s, 1970s, 1980s, 1990s and 2000s. There were several criteria in selecting the questions:

- Where relevant, questions were always taken from the highest tier papers, and from chemistry papers examining for the award of separate science GCSE. The material covered differs between awarding bodies as well as between decades.
- The examination was mainly to be answered online and marked electronically; therefore, long qualitative questions were unsuitable. A relatively high proportion of questions with quantitative analysis were selected to help assess trends in the numerical skills of students.
- Questions were preferred if they could be directly, or indirectly, related to modern challenges that chemists will have to face (including energy, environment, water and food), or that would assess the problem-solving and mathematical skills of the candidates.

The paper was divided into two sections. Section A was compulsory; to be eligible to win, candidates had to attempt all questions in this particular section – this was to encourage all students to experience questions from each decade. Following this, Section B was a 'bonus section', where as many questions as possible were to be attempted in the allotted time. The number of marks assigned to each question was based on estimates of the relative work deemed for completion, taking advice from an experienced chemistry examiner. Students were purposefully stretched in this examination and were required to complete questions quickly.

A total of 8 marks were available from each decade in Section A (40 in all), and approximately 24 marks were available from each decade in Section B (121 in all). In consolidating results, totals out of 161 were normalised with respect to a maximum score of 100%. Questions from different decades were positioned randomly in each section, so that participants would not be able to identify the source decade. The examination was set with a maximum of two hours to complete the paper. The examination questions and answers are given in Appendix A along with details of the examination boards and question classification. Throughout this report examples of questions highlighting a concept are given in parentheses.

To ensure that all candidates sat the paper simultaneously, the online version of the exam was not available for access until 12.00 noon on 27th June. Hard copies had been made available to the supervising teacher of each school several hours beforehand, and then distributed to the participants at the start of the examination, so that a permanent record of their detailed working during the two hours could be kept. Papers from the highest scorers were scrutinised by the RSC prior to formally announcing the winners.

Where there was an interruption or delay in the online access (which was the case for a number of schools), participants could continue to work on the paper version, and could submit their completed scripts in this form instead. Submissions were, therefore, ultimately a combination of electronic and paper versions.

Results from 333 schools were received, with over 1,300 students participating in total. An average of four students was accordingly entered per school, many nominating their most talented chemistry students. The maximum number of students entered from any one school was 25, but the majority (75%) entered just one student. Further information on the schools and students entered are given in Appendix B.

A small proportion of students entered were from year 10 (approximately fifty), where the average age would be 15 years old, but the precise number is unknown as not all schools disclosed the year group of their pupils. The majority of year 10 students, however, would not have studied the complete GCSE specification. Overall, students would have studied for a variety of awarding bodies, with many not having studied triple-award science, where chemistry, physics and biology are taught and examined separately. Many from Scotland would have studied for Scottish Standard and Intermediate Grades. A number of independent schools would have worked to the International GCSE (IGCSE) specification, which many teachers report is more rigorous and prepares students better for their subsequent Advanced Level (A-level) course than the standard GCSE specification.

Candidates were instructed to work individually, supervised under examination conditions. A periodic table of the elements was provided, candidates were allowed to use calculators, and relevant physical and chemical data were given in the questions, along with the units and number of significant figures required for completing each question.

The results collated from all schools were marked and analysed. The winning candidates, along with their schools, are listed in Appendix D.

2. Analysis of Results and Trends

Responses to questions have been analysed looking at individual submissions and trends across the decades. The precise marks allocated to each decade were not exactly equal; therefore, where decades are compared, results are weighted accordingly and the percentage of available marks awarded is quoted.

Questions and Curricula

The specifications for O-levels and GCSEs have changed over the decades, and a number of questions from the earlier periods are not covered in modern specifications. Some of the questions required understanding of concepts which, for a few topics examined, are no longer taught; only students reading outside or beyond the current defined specifications would be expected to have answered these questions well. An example is a question on enthalpy bond energies within the molecule benzene (B27), which is now principally an A-level question.

Other questions may have used an unfamiliar format or wording; however, in many cases, the correct answer could be reached by extracting the relevant information from the question. This includes questions on gas volumes where the relationship between the number of moles and the volume occupied is given in the question (B5, B12), but this relationship and the meaning of r.t.p. (room temperature and pressure) may have only been taught to those studying GCSE chemistry as a separate science.

Some questions would need to draw on information now part of the physics specification, such as those on radioactive decay (A7) and those on the currents involved in electrolysis experiments (B30). To answer such questions successfully, significant lateral thinking would be needed, bringing together knowledge from both chemistry and physics.

Although the specifications of different examination boards vary, most of the participants would not have been significantly hindered by the format of the majority of questions. Appendix B includes a classification to help clarify those questions strictly beyond the present chemistry syllabuses.

Key Trends

Key trends from the competition are summarised below and are shown graphically in Appendix C; these figures will be referred to where relevant in this section.

- The winning overall mark was 94%, and the average mark was 25% (23% for females, 27% for males, 33% for independent schools and 23% for state schools). This was from a total of 1,301 participating pupils, 75% from state schools and 25% from independent schools.
- The average mark for the 1960s questions was 15%, and for each subsequent decade this rose steadily, reaching 35% for the 2000s. Similar trends were seen for male and female students from state and independent schools (Figure 1).

- The trend across the decades was, on average, similar from students of all abilities (Figure 2). Students scoring in the top-5 percentile scored an average of 86% in questions from the 2000s, compared to 58% in questions from the 1960s. The largest step was between questions from the 1980s and 1990s, corresponding to the period when O-level examinations were replaced by GCSEs, and examination topics changed considerably. There was only a small increase from the 1990s to the 2000s, which suggests no significant change in the difficulty of numerically-based questions in GCSEs over the last twenty years, although these have been relatively simple, and now form a very minor proportion of modern examination papers.
- Candidates were under some time pressure, which is illustrated by the slightly higher average score of 33% over the compulsory Section A (first 10 questions). Here an average of 42% of marks was scored in questions from the 1990s and 2000s, compared to an average of 27% of marks from the earlier decades. There was not a large enough sample of questions from this section to carry out meaningful statistical analysis.
- Questions which required a single-step mathematical operation were overall answered the most successfully. This was followed by those questions that needed no mathematics to answer them, but depended on recall or expressing an opinion. Questions which required multiple calculation steps, without being led through each step, were generally answered least well (Figure 3).
- Qualitative answers requiring an understanding of 'how science works' were generally answered very well, reflecting the change in emphasis on the modern science specifications.
- The overall distribution of marks was skewed, with 90% of candidates scoring 50% or less (Figure 4).
- Males consistently answered questions better than females (Figure 1b and 3b).
- Candidates from independent schools scored significantly higher than candidates from the state sector on average (Figures 1c and 3c).

A breakdown of all questions, colour-coded by source decade, is shown in Figures 5 and 6, highlighting some of the questions of particular note.

Characteristics of Questions Answered Well

There were only a few questions, or parts of questions, where over 60% of students answered them well. These were questions requiring no mathematics, or questions requiring a single one-step mathematical operation (Figure 7).

For example 82% could correctly identify the quantity of sodium nitrate that would dissolve in 10 g of water at 30 °C given a table of solubility for 100 g water over a range of temperatures (A2ii). The proportion that could calculate how long it would take for a radioactive element to decay to a quarter of its mass, given the "half-life", was 77% (A7i).

A qualitative question relating to the properties of lemonade ingredients was the question answered best overall (B7), with 72% of available marks awarded for this entire question. (Within this question, 81% correctly identified sodium as the metal in sodium benzoate, but only 61% correctly gave the number of elements present in this compound, with the formula $C_6H_5CO_2Na$ given.)

Given the element's atomic number and mass number, 69% of pupils were also able to answer a question on the number of protons, neutrons and electrons present in an atom (B16i).

Qualitative questions relating to today's issues were also generally answered very well, with 73% successfully arguing the advantages and disadvantages of nuclear versus coal-burning power stations (A4c).

Characteristics of Questions Answered Poorly

The majority of question parts which required a multi-step mathematical operation were answered correctly by fewer than 30% of pupils (Figure 7).

Most candidates were unable to answer questions where they needed to know that equal volumes of gases at the same temperature and pressure contain the same number of molecules. This is something which is encountered only in higher tiers of specifications (B3, B6, B11, B29).

Questions that described unfamiliar experimental setups (such as testing for sulfur dioxide in polluted air, A8), or those where students had to extract the relevant information from the text (for example to identify the properties of unknown compounds, A5, B26), often seemed to cause difficulties. This phenomenon, which will be familiar to many examiners and teachers, occurred even when students were clearly led through the questions, with many students seemingly confounded by more involved descriptive questions. An example is a question on testing the purity of water used in dialysis, with step-by-step titration calculations (B20).

The question answered least successfully, with just 1% of the available marks awarded, was on the bond energies and enthalpy change of formation for a benzene molecule (B27). Although this was an O-level question from 1985, this is now part of the A-level specification and represents a very high level of difficulty for candidates.

Typical Errors

A common error in mathematical questions was to answer a question to the wrong order of magnitude, due to an error in the calculation or through misinterpretation of units and concentrations. Candidates also often failed to deal with the number of moles correctly, leading to answers which were incorrect by an integer factor.

Errors in simple mathematical calculations were common. For example, just 56% of participants successfully determined the relative formula mass of $MgCl_2$, given the relative atomic masses for Cl and Mg (B17). Only 52% successfully calculated the percentage mass of phosphorus in calcium phosphate, again with the formula and relative atomic masses given (A3).

Twelve students gave answers of over 1,000 amperes for electroplating (two of which answered 3 million amps). Whilst this is, perhaps, to be expected if students have yet to be taught electrochemistry, it is a cause for concern if students are unable to recognise or validate whether their answer is of a sensible order of magnitude.

3. Wider Context

In delivering support to industry and academia in the chemical sciences, the RSC is aware of many of the issues these sectors face. Employers in the UK need graduates who are competent in quantitative and analytical methods and better problem-solving skills. The absence of these attributes in some graduates is a widespread concern.[5]

To address these issues, it is necessary to look at the various stages of the UK education system that affect the eventual calibre of UK chemistry graduates.

Higher and Further Education

Universities are striving to supply graduates with the skills needed and expected. However, many students have not reached the appropriate level of mathematics at the start of their chemistry course; furthermore many students lack competence in learning independently or are unable to persevere with difficult concepts.[6] Universities find that although students can often solve a mathematical formula, they struggle to apply the formula to the information given in a problem.

Chemistry departments increasingly have to consider preparatory mathematics courses for science students who are not equipped with the skills required, and universities are reluctant to insist on A-level mathematics as a prerequisite for chemistry courses as they fear a decline in applications. Imperial College has indicated a need to set its own entrance examinations, to distinguish the most talented students.

A recent study of A-levels has pointed to the sciences and mathematics, along with languages, as being more difficult than other subjects.[7] In order to meet the UCAS-point entry requirements, this apparently leads to many chemistry students entering universities with an 'unusual' combination of A-levels. Between 1996 and 2007 the number of 17 year olds taking mathematics has dropped, and those without maths may genuinely struggle with the simplest aspects of arithmetic and algebra in A-level chemistry.[5]

[5] *Skills for the 21st Century Chemicals Industry*, Skills, Network Group of the Chemistry Leadership Council (2004)

[6] *School-to-university transition: comparison of the A-level chemistry specifications with year 1 at university.* Final Report of the 'Syllabus Group' (Sub-group of Curriculum Development: Strand 3 of Chemistry for our Future

[7] *Relative difficulty of examinations in different subjects*, R. Coe, J. Searle, P. Barmby, K. Jones, S. Higgins, Curriculum, Evaluation and Management (CEM) Centre at Durham University (2008)

GCSEs

Question styles have changed over the decades. There is now a greater emphasis on the processes and implications of scientific enquiry ('How Science Works'), particularly for the new Key Stage 4 specifications taught from 2006, first being examined in 2008. Such changes in the specification should be welcomed; however it is important that this can include stretching talented students, and preparing them for a possible career in science.

The 2008 GCSE results for chemistry and science were in keeping with the continuing remarkable performance of pupils reported throughout the UK media. Of 77,000 taking chemistry as a separate subject, over 52% achieved the top grades of A* or A. Of 538,000 taking the broader, science paper based on the new specification, 13% achieved these grades, 59% obtained grade C or better (designated a 'good' pass), while 89% were awarded a pass, (grade E or better). In contrast, the typical annual intake is 4,000 students into UK undergraduate chemistry courses, although there are many other students with GCSE chemistry qualifications who enter other quantitatively-based courses or occupations.

Overall, the 2008 results mean that over 400,000 pupils will have received a 'good' pass in a science GCSE. This is usually taken as a mark of basic scientific literacy and is making some decision-makers query why, with this extraordinary success, so much government and other funding is being directed to additional science-technology-engineering-mathematics (STEM) initiatives, within and outside the classroom. Whilst increased investment in education should lead to improved student attainment over the long term, we consider much of the recent progress relative to previous years to be illusory, concealing as it does the most fundamental deficiencies in the quantitative aspects of science education.

In recent years, an increased emphasis has been placed on the context and application of scientific knowledge to problems in the real world. Whilst this represents an improvement over more traditional educational approaches, which relied heavily on recall of isolated chemical facts, the lack of quantitative content in the GCSE curriculum means that an A or A* grade can be attained with little manipulation of numbers. The inevitable outcome is that, with so little emphasis on the quantitative aspects of science, pupils will not be able to develop better logic and problem-solving abilities, and their appreciation of the context of science will be, at best, superficial.

Furthermore, the constraints of curricula, and the pressure to achieve good rankings in league tables, do not support teachers who may wish to encourage students to be stretched beyond what is needed to achieve high grades. In this competition this is illustrated by the small number of pupils scoring highly, despite many schools indicating they had nominated their most talented young chemists. Of note is the small number that did do exceptionally well, but from a proportionately small number of schools. These pupils demonstrated they were capable of lateral thinking, extracting relevant information and learning beyond the current GCSE specifications. School and teaching resources are central to their achievements.

Concerns remain that with current pressure on teachers and resources, there is no scope for the mathematical content of lessons to be broadened. There are limitations in pupils' fundamental mathematical abilities which are accompanied by an apparent minority of science teachers having a qualification (to degree level) in a mathematical-based science.[8] Given this state of affairs, it is no surprise that a recent report by Ofsted found that as many as half of the schools in England are failing to properly equip pupils mathematically for their futures, largely due to an emphasis on 'teaching to the test'.[9] Additionally, science and mathematics lessons in schools are often not coordinated, so that pupils are not prepared with the mathematical techniques required before they are encountered in science lessons.

Many teachers commented on the enthusiasm of their pupils, both before and after the Five-Decade Challenge, even though the competition had been extremely demanding (some comments are included in Appendix E). An underlying theme was that current GCSE examinations in chemistry do not stretch able pupils. Some independent schools are abandoning GCSEs in favour of what they feel are more rigorous alternatives.[10]

For many, the perceived inflexibility of the curriculum and the undemanding nature of GCSE exams (as well as the increasing trend of 'teaching to the test' to increase success rates), are preventing us from fully realising the potential of our pupils.

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[8] *The UK's science and mathematics teaching workforce*. A Royal Society state of our nation report. (2007)
[9] *Mathematics: understanding the score*. Ofsted (2008)
[10] *The Times* 30 August 2008

Feeding into GCSEs, the curriculum and assessment for science and mathematics needs to be reviewed at an earlier level. The recently abandoned national examinations set for 14-year olds in STEM subjects (Key Stage 3 SATS) needed to be improved significantly to test pupils' grasp of the full range of basic mathematical principles which form the foundation of further study. As an example, a 1998 revision book identifies sixteen quantities, with units and associated mathematical operations,[11] yet this year's examination just referred to the four most simple parameters, with little numerical demand.

Whilst a critical view of UK education at every level is important, it is essential to set this in an international context when considering the future of UK science. The international position of the UK in the scientific ability of its fifteen year-olds lies outside the top 10, according to the Programme for International Student Assessment (PISA) rankings by the Organisation for Economic Cooperation and Development. The UK should aspire to compete with the top 10 nations if we are to create a truly sustainable knowledge economy, and this will require an in-depth reassessment of our entire education system.

4. Way ahead

It is important to continuously reassess not only the curriculum for chemistry and science but the attitudes to learning and the training and encouragement available to the UK's future scientists. Whilst the current emphasis on the context of science should enable all pupils to participate in public debate, it is vital that those pupils who have the ability to pursue a scientific career can experience an education that prepares them for this in the best way possible.

We must listen to the needs of industry and academia, and appreciate the global changes in the science community in order to reach national agreement on what pupils should be able to do at various ages and ability levels. In line with the Leitch Review of Skills, it is important to assess standards at the top level internationally.[12]

The application of logic and mathematics to scientific questions should be a key feature in science education, which will help improve valuable and transferable problem-solving skills, will reinforce the techniques learnt in mathematics, and will allow students to appreciate the quantities and scale of physical parameters. The chemistry curriculum taught in schools needs to be reviewed with the objective of addressing the skills-gap in employment, and to ease transitions at various stages of education.

Parallel to this, assessment procedures need to be critically transformed to meet the needs of pupils, schools, universities and employers, with a holistic view of the future development of the UK science-base. Where necessary, a new grading system should be introduced to differentiate exceptional performance more meaningfully with rigorous checks to ensure that standards are maintained.

There is a recognised need for an investment in teaching resources and for an increase in chemistry teachers with appropriate qualifications. The independent sector is known to have more teachers with higher degrees and more teachers with degrees in maths, science and engineering. This gap between the state and independent sectors needs to be addressed.[13] The way that science and mathematics are taught must be reviewed and continuing support and professional development must be available to teachers, particularly for those for whom chemistry is not their degree specialism.

Common themes in science and mathematics curricula should be evaluated such that a coordinated approach to teaching these disciplines can be considered. Where possible, pupils should be equipped with fundamental mathematical skills before encountering them in science lessons and science classes should be used as an opportunity to reinforce techniques, demonstrate the relevance of mathematics and develop essential problem-solving skills.

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[11] *Key Stage Three in Science, The Revision Guide* (1998), P. Gannon, Coordination Group Publications Ltd.

[12] *Leitch Review of Skills: Prosperity for all in the global economy – world class skills*, Final report (2006)

[13] *Competition for Private and State School Teachers* (2008), Centre for the Economics of Education, London School of Economics http://cee.lse.ac.uk/ceedps/ceedp94.pdf

Appendix A – Questions and Answers

For the purpose of the online competition, where necessary the units and the number of significant figures required for the answers were given in the questions.

Section A - Compulsory Section

A1. 2005

A titration can be used to find the concentration of a solution.

In a titration, 22.0 cm^3 of hydrochloric acid is required to neutralise 25.0 cm^3 of calcium hydroxide solution.

The concentration of the hydrochloric acid is 0.001 mol/dm^3.

The equation for the reaction is:

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

(Relative atomic masses: H = 1; O = 16; Ca = 40)

(i) How many moles of hydrochloric acid are present in 22.0 cm^3 of the acid solution?
(ii) With how many moles of calcium hydroxide will 22.0 cm^3 of this acid solution react?
(iii) What is the concentration (in mol/dm^3) of the calcium hydroxide solution?
(iv) What is the concentration (in g/dm^3) of the calcium hydroxide solution?

A2. 2005

The solubility of sodium nitrate in water, at various temperatures, is given in the table.

Temperature (°C)	0	10	20	30	40	50	60
Solubility (g/100 g water)	72	78	84	95	104	112	124

(i) A saturated solution of sodium nitrate containing 25 g of water is cooled from 50 °C to 20 °C. Calculate the mass of sodium nitrate which would crystallise.

A mixture **X** containing 10 g of water and 10 g of sodium nitrate at 30 °C is prepared. After stirring, some of the solid is seen to remain at the bottom of the flask.

(ii) What is the maximum mass of sodium nitrate which would dissolve in 10 g of water at 30 °C?

A3. 1965

Calculate the percentage by mass of phosphorus present in calcium phosphate, $Ca_3(PO_4)_2$. Relative atomic masses: Ca = 40; P = 31; O = 16.

A4. 1994

The amount of energy released by the combustion of carbon is -394,000 J mol^{-1}.

(a) Calculate the mass of coal which must be burned in a coal-burning power station in order to liberate 10^9 J of energy (which is the amount liberated on the fission of 10 milligrams of ^{235}U). Assume that coal is pure carbon. (Relative atomic mass: C = 12)

(b) Calculate the mass of carbon dioxide that would be released into the atmosphere during the combustion in (a) above.
(Relative atomic masses: C = 12; O = 16)

(c) State one environmental advantage and one environmental disadvantage of nuclear power stations against coal-burning power stations. *(in fewer than 8 words for each)*

A5. 1975

Equal volumes of the vapour of an alcohol **X** and of oxygen gas have the same mass at the same temperature and pressure. Oxidation of **X** gives a weak acid **Y** of molecular formula H_2CO_2.
2.3 g of **Y** neutralise 50 cm^3 of 1.0M sodium hydroxide.
(Relative atomic masses: C = 12; H = 1; O = 16)

(a) What is the relative molecular mass of **X**?

(b) What is the relative molecular mass of the acid **Y**?

(c) What volume of 1.0M sodium hydroxide would be needed to neutralise one mole of **Y**?

A6. 1985

Nitrogen can be obtained by heating solid ammonium dichromate(VI), $(NH_4)_2Cr_2O_7$.

Chromium (III) oxide (Cr_2O_3) and steam are the only other products of this reaction.

Construct the equation, including state symbols, for the action of heat on ammonium dichromate(VI).

(ii) What mass of ammonium dichromate(VI) must be completely decomposed in order to obtain 1 g of steam? (Relative atomic masses: N = 14; H = 1; Cr = 52; O = 16)

A7. 1995

The "half-life" of a radioactive element is the time it takes for a given mass of that element to decay to half its original mass.
The half-life of radon is 3.8 days.

(i) How long would it take for 10g of radon to decay to 2.5g of radon?

(ii) Which of the atoms labelled X below are isotopes of radon?

❑ ${}^{218}_{86}X$ ❑ ${}^{221}_{87}X$ ❑ ${}^{222}_{86}X$

❑ ${}^{223}_{88}X$ ❑ ${}^{223}_{87}X$ ❑ ${}^{226}_{88}X$

A8. 1988

One method of testing for sulfur dioxide in a sample of polluted air is to bubble the air through an acidified solution of potassium dichromate(VI).

The ionic equation for this reaction is given below

$$3SO_2 + Cr_2O_7^{2-} + 2H^+ \rightarrow 3SO_4^{2-} + 2Cr^{3+} + H_2O$$

A solution contains 0.1M of dichromate(VI) ions. Calculate the minimum volume of this solution required to remove the sulfur dioxide from 2 dm^3 of polluted air which contains 3.6% by volume of sulfur dioxide, measured at r.t.p.
One mole of any ideal gas occupies 24 dm^3 at r.t.p. (room temperature and pressure)

A9. 1975

A certain quantity of electricity liberates 9 g of aluminium. The mass of copper liberated from copper(II) sulfate solution (Cu^{2+} ions) by the same quantity of electricity is: (Relative atomic masses: Al = 27; Cu = 64)

❑ 9.0 g

❑ 21.33 g

❑ 32.0 g

❑ 42.67 g

❑ 64.0 g

A10. 1965

100 g of water at 15 °C dissolves at saturation 37 g of sodium chloride and 25 g of potassium nitrate but at 70 °C the corresponding weights are 38 g and 140 g per 100 g of water respectively.

100 g of a mixture of the above two salts, in equal proportions by weight, are shaken with 100 g of water at 70 °C, until equilibrium is reached. The solution is filtered hot. The hot filtrate is slowly cooled to 15 °C and again filtered. The final filtrate is evaporated to dryness.

What will be the weights and composites of the three residues, assuming that no solution is left in either of the filter papers?

Section B – Bonus Section

Candidates were asked to attempt as many questions in this section as possible

B1. 2005

One of the hydrocarbons in petrol is octane.

This equation shows the combustion of octane:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

What mass of carbon dioxide is produced for every tonne of octane burned in this reaction?
(Relative atomic masses: H = 1; C = 12; O = 16)

B2. 1988

In an experiment to determine the amount (in moles) of 'water of crystallisation' contained within 1 mole of hydrated zinc sulfate $ZnSO_4.xH_2O$, a pupil heated some hydrated zinc sulfate crystals until all of the water of crystallisation had been driven out. The following results were obtained:

Mass of empty crucible = 22.87 g

Mass of crucible + crystals = 25.86 g

Mass of crucible + anhydrous salt = 24.55 g

Use this information to calculate the integer x in the formula $ZnSO_4.xH_2O$
(Relative atomic masses: H = 1; O = 16; S = 32; Zn = 65)

B3. 1975

1.0 dm^3 of ammonia was passed over heated copper(II) oxide (CuO). The nitrogen formed (measured at the same temperature and pressure as the ammonia) would have a volume of:

- ❑ 250 cm^3
- ❑ 500 cm^3
- ❑ 750 cm^3
- ❑ 1000 cm^3
- ❑ 2000 cm^3

B4. 1995

1.44 g of an oxide of copper gave 1.28 g of copper on reduction. What is the formula of the oxide? (Relative atomic masses: Cu = 64, O=16)

- ❑ CuO
- ❑ Cu_2O
- ❑ CuO_2
- ❑ Cu_3O
- ❑ CuO_3

B5. 1965

(i) Calculate the maximum weight of barium sulfate, $BaSO_4$, that can be precipitated by 100 cm^3 of 0.05M sulfuric acid. (Relative atomic masses: Ba = 137; S = 32; O = 16)

(ii) Calculate the maximum volume of hydrogen, measured at r.t.p., that can be liberated by the action of 100 cm^3 of 0.5M hydrochloric acid on magnesium.
One mole of any ideal gas occupies 24 dm^3 at r.t.p.

B6. 1975

The volume of 8.0 g of oxygen is 7.50 dm^3 under certain conditions. What would be the volume of 8.0 g of methane under the same conditions? (Relative atomic masses: H = 1; C = 12; O = 16)

- ❑ 3.75 dm^3
- ❑ 7.50 dm^3
- ❑ 11.25 dm^3
- ❑ 15.00 dm^3
- ❑ 18.75 dm^3

B7. 1995

The ingredients in lemonade are:

A *carbonated water*	B *sugar*
C *glucose syrup*	D *citric acid*
E *flavourings*	F *acidity regulator (sodium citrate)*
G *preservative (sodium benzoate)*	H *artificial sweetener (Saccharin)*

Use the list of ingredients above to help you to answer this question:

Which is the substance in lemonade which

(i) could be fermented into alcohol?

(ii) will turn blue litmus red?

The preservative in this lemonade is sodium benzoate. Its formula can be represented as:

$$C_6H_5CO_2Na$$

(iii) Name the metal present in the compound.

(iv) State the number of different elements present in the compound.

B8. 1988

The action of heat on sodium hydrogencarbonate is represented by the following equation:

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

(Relative atomic masses: H = 1; C = 12; O = 16; Na = 23)

(i) Calculate the mass of one mole of carbon dioxide.

(ii) Calculate the mass of one mole of sodium hydrogencarbonate, $NaHCO_3$.

(iii) Calculate the number of moles of sodium hydrogencarbonate in 4.2 g.

(iv) How many moles of carbon dioxide are formed from 4.2 g of sodium hydrogencarbonate?

(v) What mass of carbon dioxide is formed from 4.2 g of sodium hydrogencarbonate?

(vi) What use does the above reaction have in baking? *(in fewer than 15 words)*

(vii) Sodium hydrogencarbonate is used in the pharmaceutical industry as a component of anti-acid medicines. Explain why it is used in this way *(in fewer than 15 words)*.

B9. 1975

Which one of the following compounds does not yield oxygen on moderately strong heating?

- ❑ Copper nitrate
- ❑ Lead nitrate
- ❑ Potassium nitrate
- ❑ Iron (III) oxide
- ❑ Lead(IV) oxide

B10. 2005

(a) Lead is extracted from the ore galena, PbS, by roasting in air to produce lead(II) oxide, PbO:

$$2PbS(s) + 3O_2(g) \rightarrow 2PbO(s) + 2SO_2(g)$$

(Relative atomic masses: Pb = 207; S = 32; O = 16)

(i) Calculate the mass of PbO produced from 2390 g of galena, PbS.

The lead(II) oxide is reduced to lead by heating it in a blast furnace with carbon:

$$PbO(s) + C(s) \rightarrow Pb(l) + CO(g)$$

(ii) Using your previous answer, calculate the mass of lead that would eventually be produced.

(b) The metal lead forms several oxides. The formula of lead oxide may generally be represented as Pb_xO_y.

To find the formula of a sample of lead oxide, a dish was weighed and the mass recorded. The dish was then filled with the lead oxide and weighed again.

The dish was then placed in a hard-glass tube and heated in a stream of hydrogen gas. The hydrogen reduced all of the lead oxide to a bead of silvery lead metal. The apparatus was allowed to cool and the dish and its contents were reweighed.

Mass of dish = 21.35 g

Mass of dish + lead oxide = 28.20 g

Mass of dish + lead metal = 27.56 g

(i) Calculate the mass of lead metal produced.

(ii) Calculate the mass of oxygen present in the lead oxide.

(iii) Using your answers to (i) and (ii), calculate the formula of the sample of lead oxide, Pb_xO_y.
(Relative atomic masses: Pb = 207; O = 16)

B11. 1985

A sample of 50 cm^3 of carbon monoxide was burned in 50 cm^3 of oxygen. What was the composition of the gas remaining after the reaction? (All measurements were made at the same temperature and pressure)

- ❑ 50 cm^3 of carbon dioxide only
- ❑ 100 cm^3 of carbon dioxide only
- ❑ 50 cm^3 of carbon dioxide and 25 cm^3 carbon monoxide
- ❑ 50 cm^3 of carbon dioxide and 25 cm^3 of excess oxygen
- ❑ 75 cm^3 of carbon dioxide and 25 cm^3 of excess oxygen

B12. 1965

10 dm^3 of nitrous oxide (dinitrogen monoxide) are passed over heated copper and the gas formed is collected. If the reaction goes to completion, and all volumes are measured at r.t.p., what is the volume of the gas collected and the mass of the copper(II) oxide formed? (Relative atomic mass Cu = 64)
One mole of any ideal gas occupies 24 dm^3 at r.t.p.

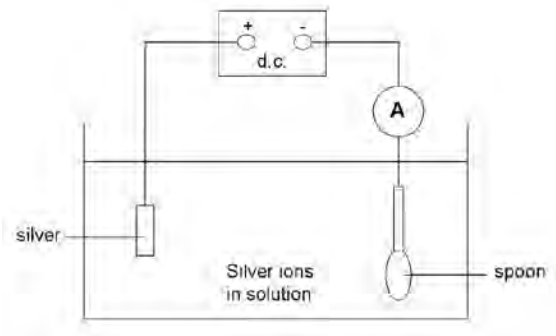
B13. 1995

Which one of the following reactions does not take place in a blast furnace

- ❑ $C + O_2 \rightarrow CO_2$
- ❑ $CO_2 + C \rightarrow 2CO$
- ❑ $2Fe + 3CO_2 \rightarrow Fe_2O_3 + 3CO$
- ❑ $CaCO_3 \rightarrow CaO + CO_2$
- ❑ $CaO + SiO_2 \rightarrow CaSiO_3$

B14. 2005

A brass spoon is to be electroplated with silver, as shown in the circuit diagram.



A constant current is used for a duration of 34 minutes.

The spoon increases in mass by 0.46 g due to the silver plating.

The equation for the reaction at the negative electrode is:

$$Ag^+ + e^- \rightarrow Ag$$

What is the value of current used?
Relative atomic mass: Ag = 108.
96 000 coulombs of electricity (1 faraday) is the charge on a mole of any singly charged entity
1 amp = 1 coulomb per second

B15. 1988

The isotope $^{14}_{6}C$ is radioactive, is a beta emitter and has a half-life of 5730 years.
Which **one** of the following statements about the isotope is true?

- ❑ It is used to generate electricity in a power station

- ❑ In 5730 years, 1 g of the isotope will decay to 0.25 g
- ❑ The mass number of the element formed by the radioactive decay is 12
- ❑ The radiation emitted will be stopped by a piece of paper
- ❑ The atomic number of the element formed by the radioactive decay is 7

B16. 1995

A radioisotope that can be found in rock is ^{238}U.

It has an atomic (proton) number of 92 and a mass number of 238.

(i) Give the number of protons, neutrons and electrons in an atom of ^{238}U

(ii) ^{238}U atoms split up to give a different element. This has an atomic (proton) number of 90 and a mass number of 234.

What is the symbol for this new element?

B17. 2005

The formula of magnesium chloride is $MgCl_2$.

Calculate the relative formula mass of magnesium chloride.

(Relative atomic masses: Cl = 35.5; Mg = 24)

B18. 1975

Industry makes use of the following processes:

A catalysis

B electrolysis

C fractional distillation

D hydrolysis

E reduction

Choose the process which is outstandingly important in the industrial preparation of:

(i) chlorine

(ii) iron

(iii) nitrogen

(iv) soap

(v) sulfur trioxide

B19. 1985

A small butane gas lighter contains liquid butane, C_4H_{10}.

Complete the following equation which represents the reaction taking place when 1 mole of butane is burned completely in air: *(**balance using whole numbers**)*

$$\ldots C_4H_{10} + \ldots O_2 \rightarrow \ldots CO_2 + \ldots H_2O$$

It was found in an experiment that when 0.02 moles of butane was burned, 32 kJ of energy were produced. Calculate the energy produced when 1 mole of butane is burned.

B20. 1995

A process called dialysis may be used for patients whose kidneys malfunction; this 'washes' their blood in a kidney machine. The water in the washing fluid has to be highly purified, especially from significant quantities of calcium ions.

The water can be purified by 'ion-exchange'. The water is passed through a resin which exchanges calcium ions for less harmful ones. If the resin is represented by *HR*, the reaction during 'ion-exchange' can be represented by the following equation:

$$Ca^{2+}\,(aq) + 2HR(s) \rightarrow 2H^{+}(aq) + CaR_2(s)$$

A 10 cm^3 sample of water known to contain Ca^{2+} ions was passed through a resin column. The water was collected and in a titration it was found to neutralise 8.0 cm^3 of 0.001 mol/dm^3 aqueous sodium hydroxide.

(Relative atomic mass Ca = 40)

(i) How many moles of hydroxide ions, OH^-, are neutralised in the titration?

(ii) How many moles of hydrogen ions are in the 10 cm^3 sample of water?

(iii) How many hydrogen ions are replaced by each Ca^{2+} ion in the resin?

(iv) How many moles of Ca^{2+} ions were in the 10 cm^3 sample of water?

(v) What is the mass of Ca^{2+} ions in 1 dm^3 of the original water?

(vi) Assuming that a dialysis patient needs water containing less than 0.01 g/dm^3 of Ca^{2+} ions, decide whether the sampled water is suitable for use in dialysis.

❑ Suitable ❑ Unsuitable

B21. 1995

(a) A 10.00 g sample of an alcohol was found, on analysis, to contain 3.75 g of carbon, 1.25 g of hydrogen, and 5.00 g of oxygen. Work out the empirical formula of this alcohol. (Relative atomic masses: C = 12; H = 1; O = 16)

(b) The table shows some bond energies, E.

bond	E/kJ per mole
C - H	413
C - C	347
O - H	464

The dissociation of ethanol is shown below.

$$C_2H_5OH(g) \rightarrow 2C(g) + 6H(g) + O(g)$$

The dissociation energy is 3234 kJ per mole of ethanol.

What is the bond energy of C – O?

B22. 2005

(a) A compound **X** contains 34.5% iron and 65.5% chlorine by mass.

What is its empirical formula?

(Relative atomic masses: Cl = 35.5; Fe = 56)

❑ Fe_2Cl_3 ❑ $FeCl_2$ ❑ $FeCl_3$ ❑ Fe_3Cl

B23. 1975

From the list of the five metals:

A calcium

B copper

C lead

D sodium

E zinc

Choose the metal:

(i) whose carbonate and hydroxide are both water soluble.

(ii) whose anhydrous chloride is a common drying agent.

(iii) which is least electropositive.

(iv) which lies between aluminium and iron in the reactivity series.

(v) which forms an oxide that can oxidise concentrated hydrochloric acid to form chlorine.

B24. 1995

A compound containing calcium has the following composition by mass:

Ca: 33.3%, S: 26.7% and O: 40.0%

(Relative atomic masses: Ca = 40, S = 32, O = 16)

The simplest formula of this compound is:

❑ CaSO

❑ $CaSO_3$

❑ $CaSO_4$

❑ Ca_2SO_2

❑ Ca_2SO_4

B25. 1975

An element *E* forms a hydride EH_4 which contains 90.0% by mass of E. If the relative atomic mass of hydrogen is 1.0, then the relative atomic mass of *E* is:

❑ 9

❑ 22.5

❑ 36

❑ 86

❑ 90

B26. 1965

An element **X** has an atomic weight of 79. When **X** is heated with hydrogen, a gaseous compound **A** is formed. This compound contains 2.47% by weight of hydrogen and has a density of 3.375 g/dm^3 at r.t.p.

X burns in oxygen forming an oxide B containing 28.83% by weight of oxygen. B dissolves in water to form a solution of a weak acid **C**. This solution will decolourise an acidified solution of potassium permanganate.

Make use of the above information to answer the following questions:

(i) Is **X** a metal or a non-metal?

(ii) What is the relative molecular weight of compound **A**?

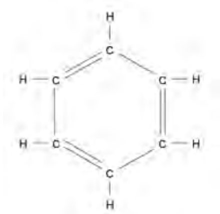
(iii) What is the formula of compound **A**?

(iv) What is the formula of the oxide **B**?

(v) How many different valencies does the experiment suggest **X** shows?

B27. 1985

(a) Use the following data to calculate the enthalpy change of formation, $\Delta H_f^\ominus$, of the cyclic triene



$\Delta H^\ominus$ (C(graphite) → C(g)) = +716 kJ/mol
Mean bond enthalpies of dissociation (in kJ/mol):

H – H : 436 kJ/mol, C – C : 346 kJ/mol, C = C : 611 kJ/mol, C – H : 413 kJ/mol

(b) Calculate $\Delta H_f^\ominus$ for benzene using the following data.

$\Delta H^\ominus$ ($C_6H_6(g) + 3H_2(g) \rightarrow C_6H_{12}(g)$) = -205.2 kJ/mol

And $\Delta H_f^\ominus$ ($C_6H_{12}(g)$) = -123.1 kJ/mol

B28. 1975

Lithium hydride (LiH) reacts with water to give hydrogen and an alkaline solution of lithium hydroxide.

Write the balanced equation, including state symbols for this reaction.

2.0 g of lithium hydride were treated with an excess of water. Calculate:

(i) the volume at r.t.p. of the hydrogen formed.
(Relative atomic masses: Li = 7; H = 1; O = 16)

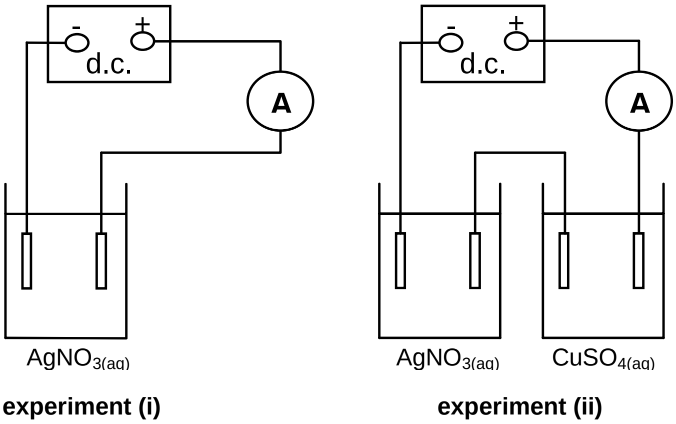
(ii) the volume of hydrochloric acid containing 73 g of HCl per dm^3 required to neutralise the resulting solution.
(Relative atomic masses: H = 1; Cl = 35.5)

B29.1965

Considering the laws of combining volumes, 200 cm^3 of a gaseous element X_2 reacted with 650 cm^3 of a gaseous element Y_2 to form 450 cm^3 of a mixture of XY_3 and Y_2. It was later found that 50 cm^3 excess of Y_2 remained unused. All volumes were measured under the same conditions of temperature and pressure.

What volume of XY_3 was formed in the reaction?

B30. 1985



The circuits of two electrolysis experiments, (i) and (ii), are shown in the diagram. The electrodes were platinum and the ammeter reading was 0.5 A in both experiments.

In experiment (i), 1.0 g of silver was deposited in 30 minutes. How long would be needed to deposit 1.0 g of silver in experiment (ii)?

❑ 20 min ❑ 30 min ❑ 45 min ❑ 60 min ❑ 90 min

Answers

A1. (i) 2.2×10^{-5} (ii) 1.1×10^{-5} (iii) 4.4×10^{-4} mol/dm^3 (iv) 0.033 g/dm^3

A2. (i) 7 g (ii) 9.5 g

A3. 20%

A4. (a) 30.5 kg (b) 112 kg (c) Sensible arguments of any advantages and disadvantages of nuclear versus coal burning power station were marked correctly.

A5. (a) 32
(b) 46
(c) 1.0 dm^3

A6. 3.5 g

A7. (i) 7.6 days (ii) $^{218}_{86}X$ and $^{222}_{86}X$

A8. 0.010 dm^3

A9. 32.0 g

A10. Residue 1: mass of sodium chloride = 12 g, Residue 1: mass of potassium nitrate = 0 g,
Residue 2: mass of sodium chloride = 1 g, Residue 2: mass of potassium nitrate = 25 g,
Residue 3: mass of sodium chloride = 37 g, Residue 3: mass of potassium nitrate 25 g

B1. 3.1 tonnes

B2. 7

B3. 500 cm^3

B4. Cu_2O

B5. (i) 1.165 (ii) 0.60 dm^3

B6. 15.00 dm^3

B7. (i) B or C (ii) D or A (iii) Sodium (iv) 4

B8. (i) 44 g (ii) 84 g (iii) 0.050 (iv) 0.025 (v) 1.1 g (vi) and (vii) Sensible answers relating to the reaction and applications referred to in the question were marked correctly.

B9. Iron(II) oxide

B10. (a)(i) 2230 g (ii) 2070 g (b)(i) 6.21 g (ii) 0.64 g (iii) Pb_3O_4

B11. 50 cm^3 of carbon dioxide and 25 cm^3 of excess oxygen

B12. 10 dm^3, 33.3 g

B13. $2Fe + 3CO_2 \rightarrow Fe_2O_3 + 3CO$

B14. 0.2 A

B15. The atomic number of the element formed by the radioactive decay is 7

B16. (i) 92 protons, 146 neutrons, 92 electrons (ii) Th

B17. 95 g

B18. (i) chlorine (ii) iron (iii) nitrogen (iv) soap (v) sulfur trioxide

B19. $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$, 1600 kJ

B20. (i) 8×10^{-6} (ii) 8×10^{-6} (iii) 2 (iv) 4×10^{-6} (v) 0.016 g/dm^3 (vi) unsuitable

B21. (a) CH_4O (b) 358 kJ/mol

B22. $FeCl_3$

B23. (i) D (ii) A (iii) C (iv) E (v) C

B24. $CaSO_3$

B25. 36

B26. (i) a non-metal (ii) 81 (iii) XH_2 (iv) XO_2 (v) 2

B27. (a) 255 kJ/mol (b) 82.1 kJ/mol

B28. (i) 6.0 dm^3 (ii) 0.125 dm^3

B29. 400 cm^3

B30. 30 minutes

Question Classification

Question	Year	Marks available	Average score	Question content	
A1	2005	4	0.96	S	c
A2	2005	4	2.56	MS	x
A3	1965	2	1.03	S	c
A4	1994	5	1.39	MN	c
A5	1975	5	1.60	SM	A
A6	1985	5	1.49	M	c
A7	1995	3	1.62	SN	p
A8	1988	3	0.26	M	A
A9	1975	3	0.39	S	p/x
A10	1965	6	1.75	M	x
B1	2005	3	0.80	M	c
B2	1988	4	0.64	M	x
B3	1975	2	0.38	S	A
B4	1995	3	1.53	M	c
B5	1965	4	0.42	M	x
B6	1975	3	0.47	M	x
B7	1995	4	2.88	N	c
B8	1988	7	3.21	SN	c
B9	1975	1	0.11	N	A
B10	2005	9	3.66	SM	c
B11	1985	2	0.32	N	A
B12	1965	4	0.27	M	x
B13	1995	2	0.71	N	C
B14	2005	4	0.30	M	p/x
B15	1988	1	0.31	N	p
B16	1995	3	1.95	SN	c
B17	2005	2	1.12	S	c
B18	1975	5	1.43	N	c/x
B19	1988	3	1.24	S	c
B20	1995	6	0.56	SNM	c/x
B21	1995	7	1.06	M	c/x
B22	2005	3	0.85	M	c/x
B23	1975	5	0.85	N	A
B24	1995	3	0.88	M	c/x
B25	1975	3	0.77	M	c/x
B26	1965	9	0.59	NS	x/A
B27	1985	8	0.06	M	A
B28	1975	7	0.20	M	x
B29	1965	2	0.10	S	x
B30	1985	2	0.25	N	p/x
Total marks available:		161			

Key for table

Question content:

N – no mathematics
S – single-step mathematical operation
M – multi-step mathematical operation

c – on current examination specifications
x – not on specifications of awarding bodies but talented students should be able to answer with the information available
A – now principally an A-level question
p – now in physics GCSE, and students would be required to draw on science knowledge across subjects

The key is generalised and does not give detail of specific examination boards or the difference in specifications for Scottish qualifications. It is assumed that the majority of students would have covered the higher tier. Not all students will have studied chemistry as a separate science; questions which are likely to only be covered by these extended specifications have been marked 'c/x'.

Examination boards:

Questions were selected, and adapted, from a range of examination boards which are listed below. Adaptations were made where necessary (for example to put questions into context where only part of a longer question was used).

A list of the examination boards used is given below:

CCEA – Northern Ireland Council for the Curriculum Examinations and Assessment
JMB – Universities of Manchester Liverpool Leeds Sheffield Birmingham Joint Matriculation Board
MEG – Midland Examining group
NEA – Northern Examining Association
NEAB – Northern Examination and Assessment Board
NISEC – Northern Ireland Schools Examinations Council
OCR – Oxford Cambridge and RSA Examinations
WJEC – Welsh Joint Education Committee

Appendix B – Participant Information

Electronic and paper manuscripts were received from 333 schools in total.

73% of these schools were state schools (including 15% grammar schools); 27% were independent schools. A list of participating schools is given on page 38.

Results from 1,301 individual participants were marked and analysed (53% male and 47% female). 75% of participants were from state schools and 25% from independent schools.

Appendix C - Results

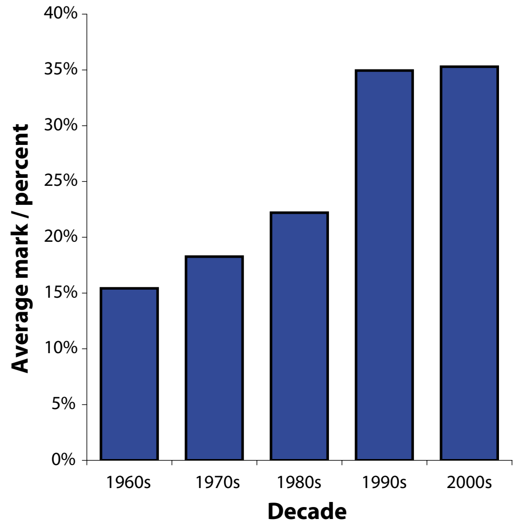


Figure 1(a) Average proportion of available marks scored for each decade.

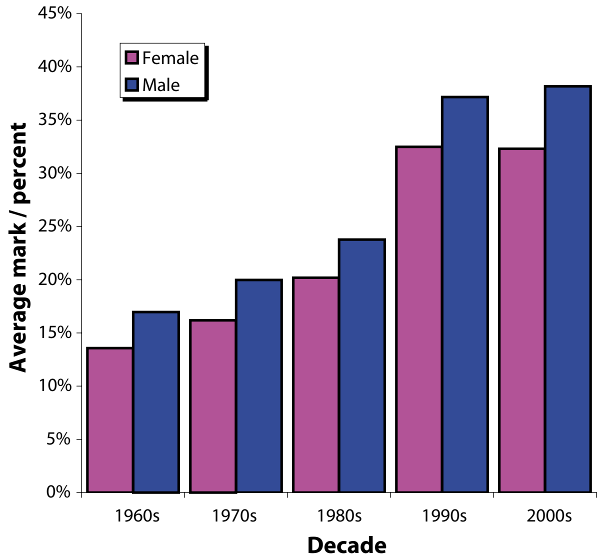


Figure 1(b) Detail of Figure 1(a) with results from males and females displayed separately.

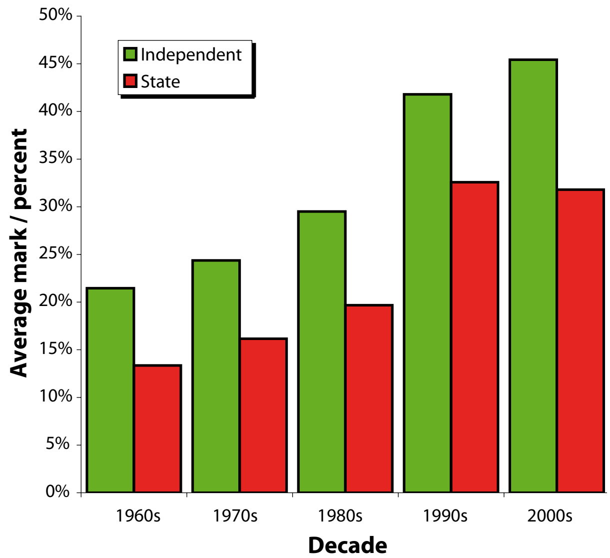


Figure 1(c) Detail of Figure 1(a) with independent and state school results displayed separately.

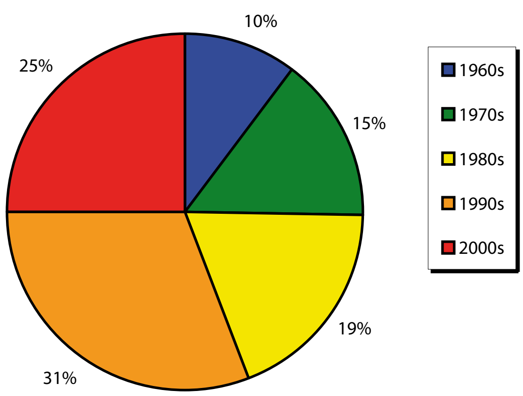


Figure 1(d) Average contribution of each decade to the overall marks scored.

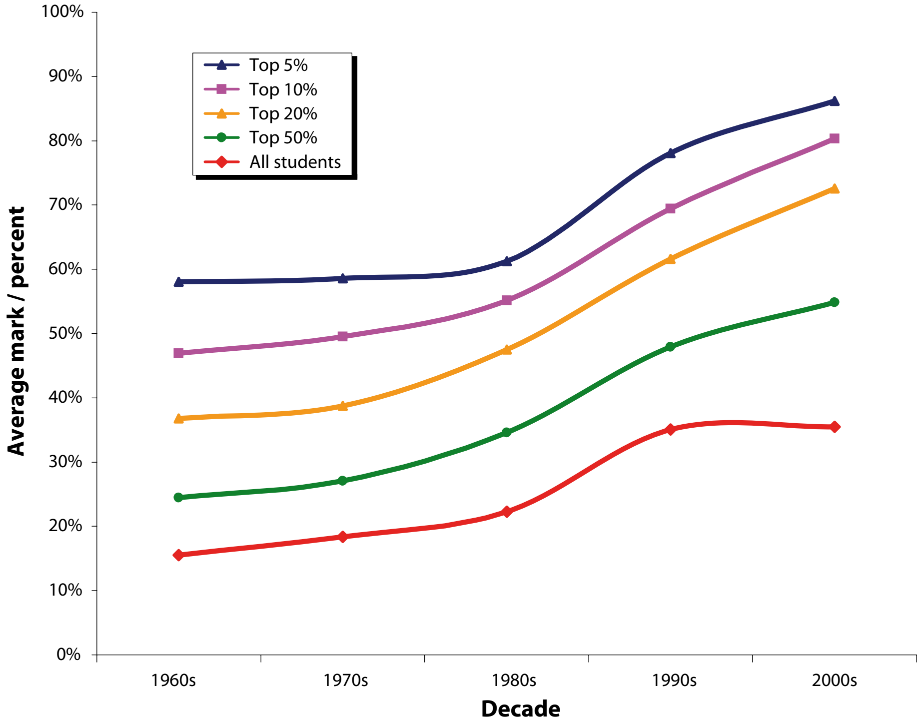


Figure 2 Average mark scored for each decade, with split detail for candidates scoring in upper percentiles. Connecting lines are provided as a guide for the eye. A similar trend across the decades is seen from candidates of all abilities with the sharpest rise between 1985 and 1995 at the introduction of GCSEs.

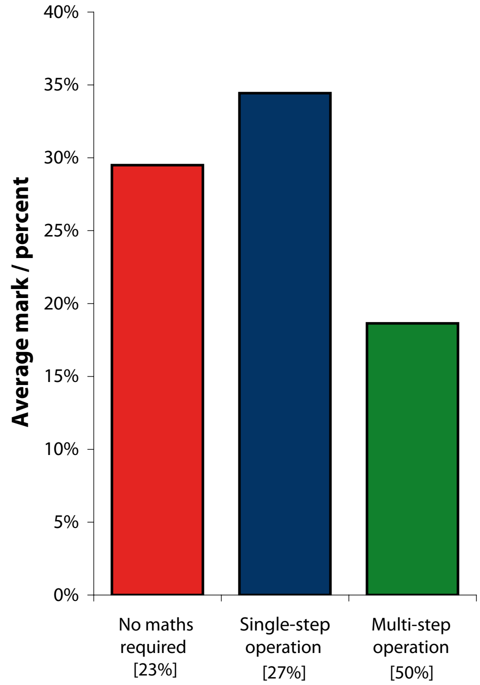


Figure 3(a) Proportion of available marks scored for questions classed by mathematical content; the total proportion of marks available in each question classification is indicated in square brackets.

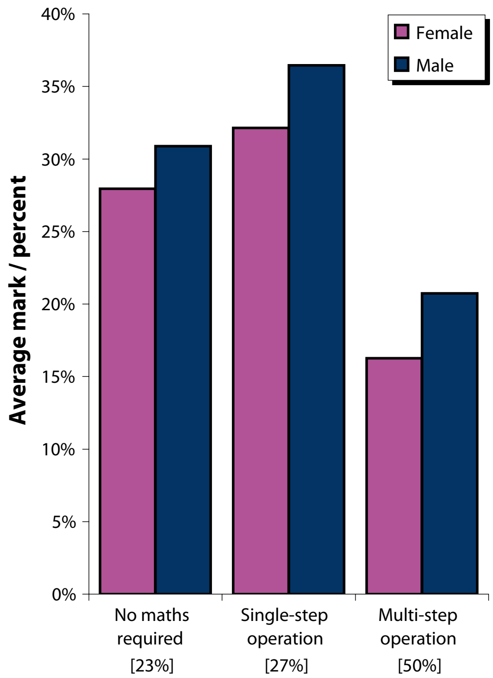


Figure 3(b) Detail of Figure 3(a) with results from males and females displayed separately.

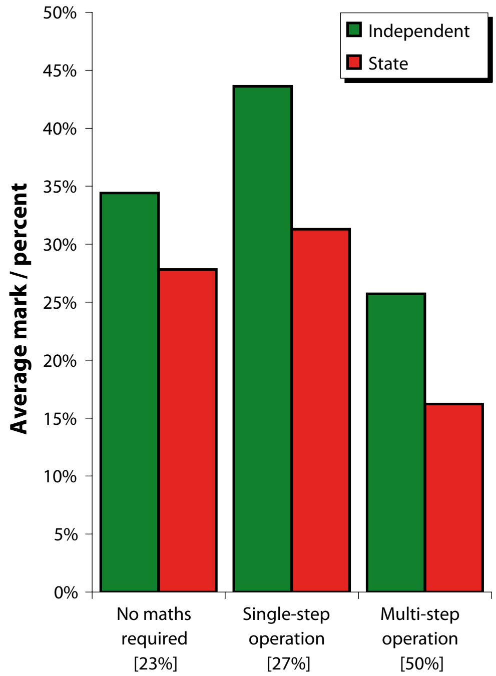
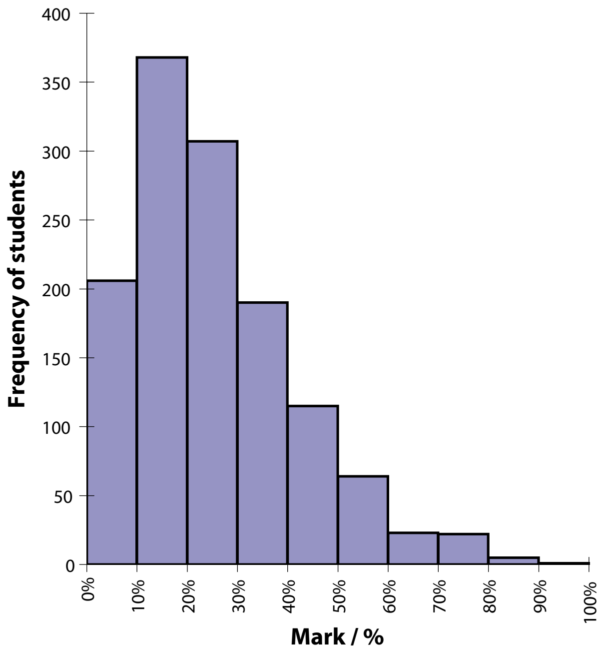


Figure 3(c) Detail of Figure 3(a) with independent and state school results displayed separately.



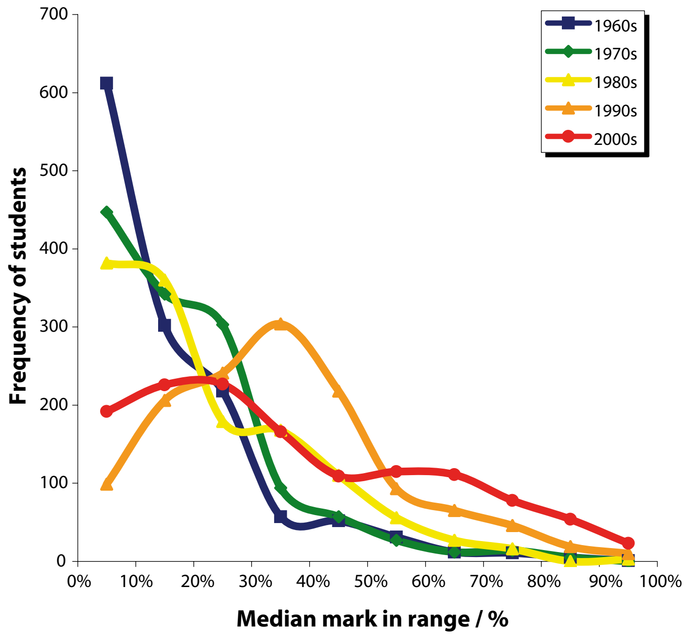


Figure 4(a) Total frequency distribution of candidates' marks.

Figure 4(b) Frequency distribution of candidates' marks for each decade of questions.

The frequency of pupils scoring within 10% intervals is plotted against the median of the interval on the horizontal axis. The connecting lines in Figure 4(b) are added as a guide to the eye. Many students scored less than 10% in questions from the 1960s, 1970s and 1980s. The distribution of marks for the 2000s is broader with a higher proportion of students getting most questions correct.

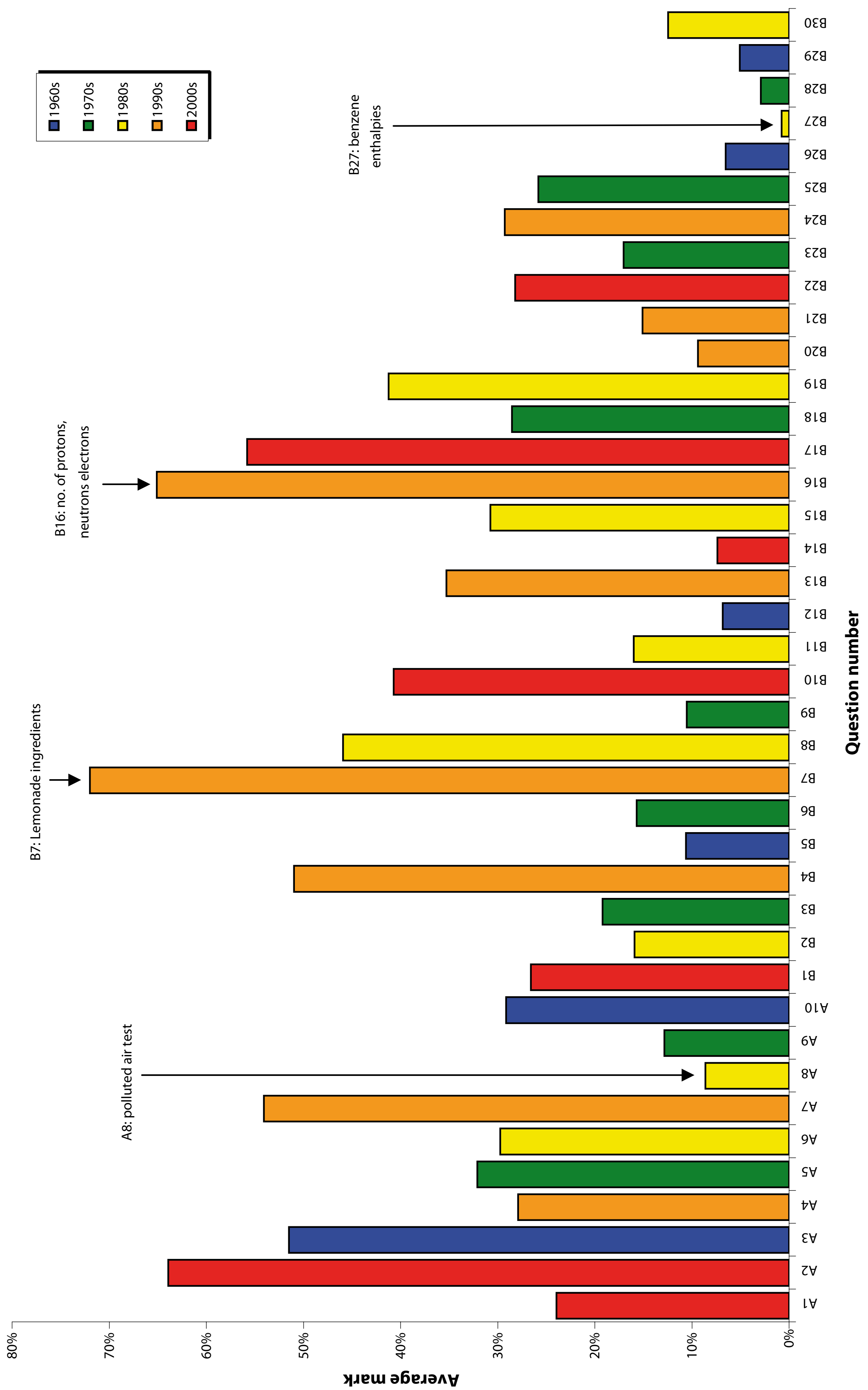


Figure 5 Average portion of available marks scored for each individual question. Note the total number of marks available was not equal for each question.

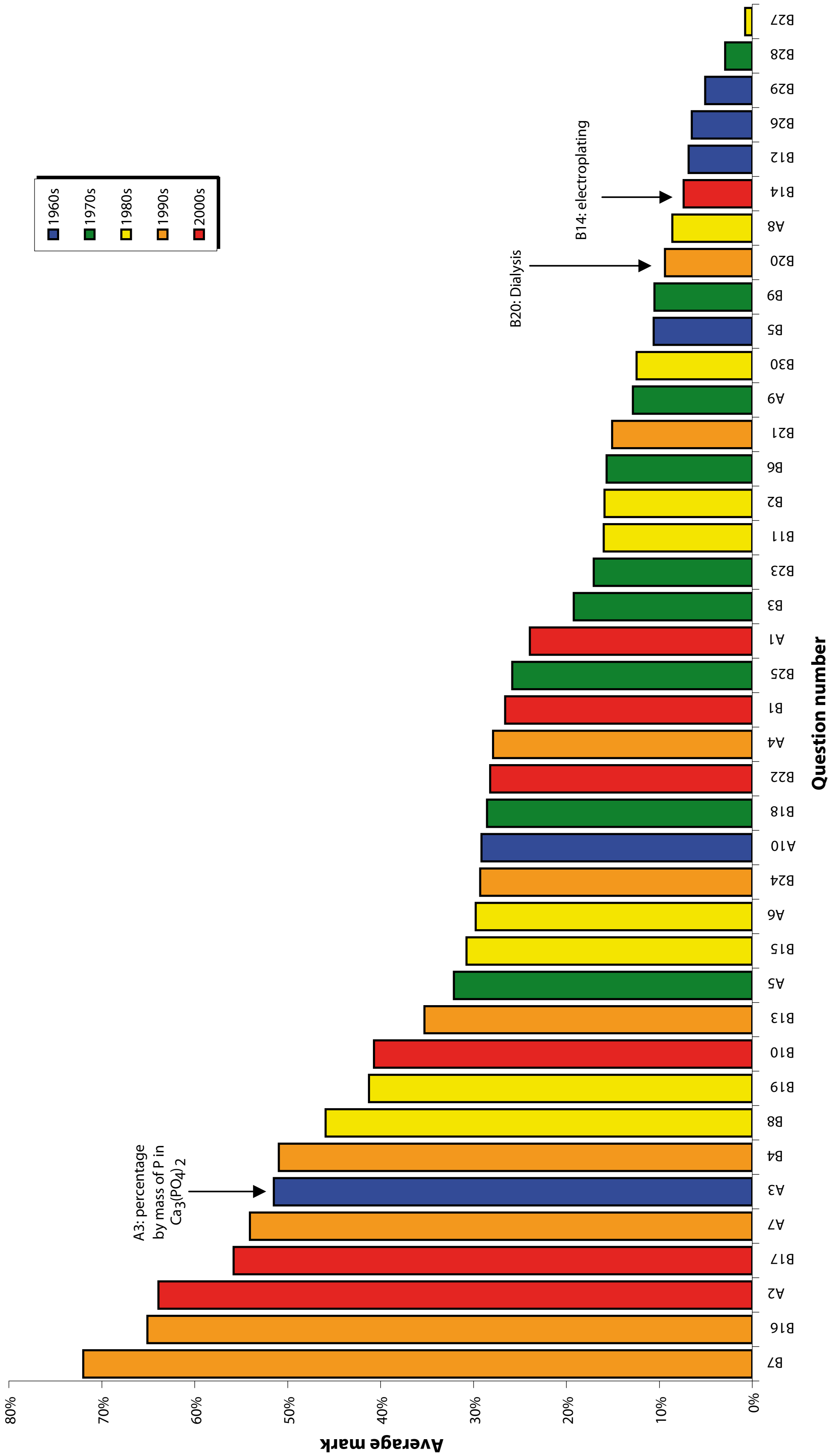


Figure 6 Average portion of available marks scored for each individual question, ordered by success and colour coded by decade.

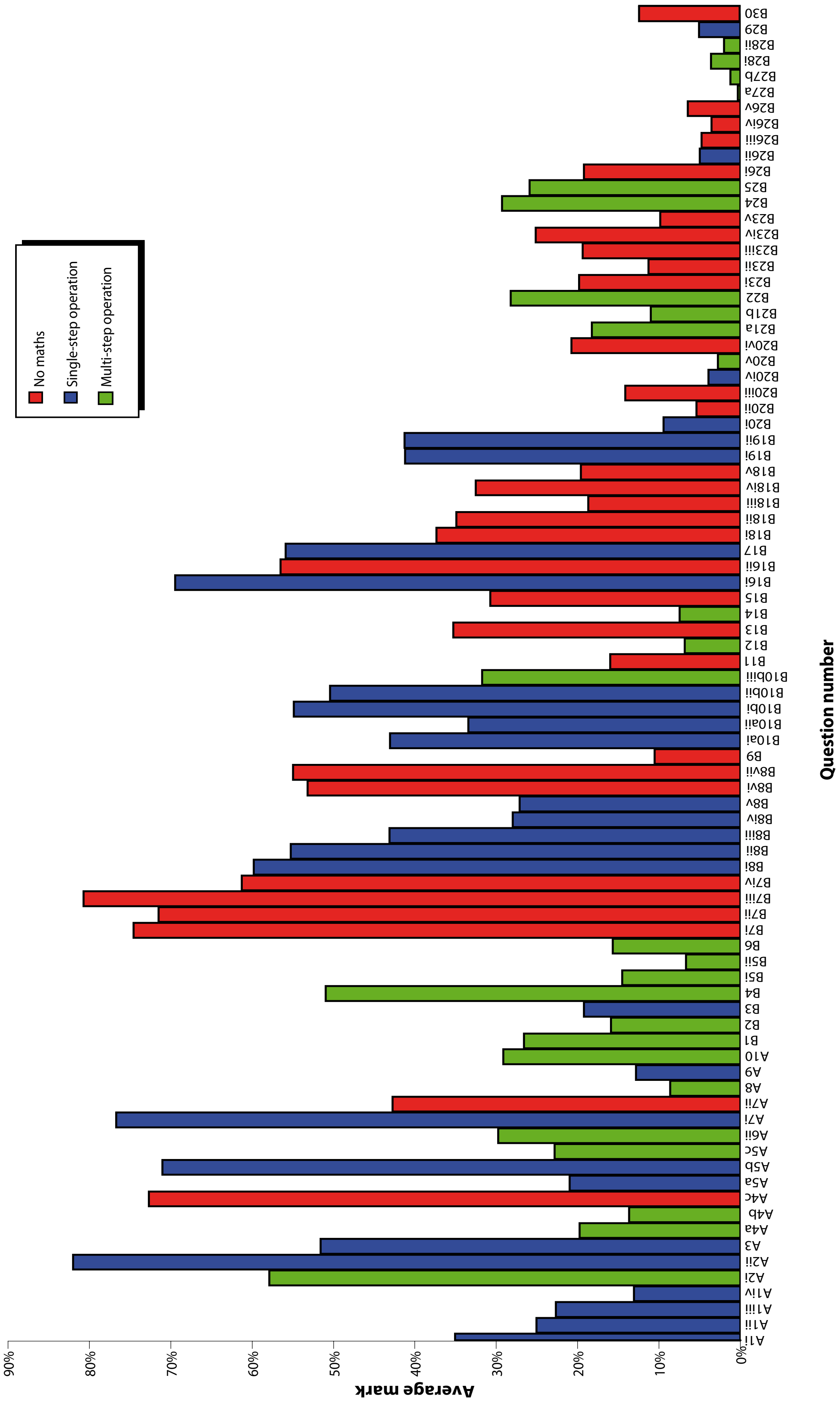


Figure 7 Proportion of total marks available scored for each question part. Since these question parts were largely marked as correct or incorrect, this closely represents the percentage of students successfully answering each part. Bars are colour coded according to mathematical content: red represents no mathematics needed; blue represents a single-step mathematical operation; green represents a multi-step mathematical operation.

Appendix D – Winners and Awarding Categories

The ten top scores are listed below, with candidate names and their schools.

Nathan Brown	93.8%	King Edward VI Camp Hill School for Boys, Birmingham
Aled Walker	85.7%	King Edward VI Camp Hill School for Boys, Birmingham
Toryn Dalton	84.5%	Bolton School Boys' Division
William Cook	83.2%	The Manchester Grammar School
Jonathan Whitby	82.0%	The Manchester Grammar School
Alex Cutbill	80.7%	Trinity School, Croydon
Martin Jackson	79.2%	The Manchester Grammar School
Gessica Howarth	78.9%	St Gerards School Trust, Bangor
Lawrence Barrott	77.6%	Royal Grammar School, Guildford
Aidan Devane	77.0%	Trinity School, Croydon
Jim Ashworth	77.0%	Trinity School, Croydon

All schools and pupils that took part were congratulated for their efforts. Beyond this, pupils scoring over 25% were awarded Merit, and those scoring over 50% were Highly Commended.

Appendix E – Teacher Comments

Before the competition:

"I think the competition is a great idea to raise the profile of chemistry"

"I would like this to become a regular feature if possible as we produce some excellent chemists."

"Thank you for this exciting challenge for the pupils"

"Thank you for confirming entry to what sounds an exciting challenge."

"The pupils are really keen"

"[We have] A year 10 [student who] loves sitting this type of challenge and who would therefore love to take part."

"I think that this is a very exciting event and thank you for taking the time to arrange it and to continue to support and promote chemistry in such novel ways."

"There has been a really positive response from our students to the idea of the competition."

"This is an interesting idea!"

After the competition:

"Thank you for the opportunity to be involved in this activity. If there are any other chemistry based or science based activities you hear of I would be really interested in involving our girls if possible"

"All my candidates found it very interesting albeit quite challenging. They were surprised at the style of wording in some of the older questions. Thank you once again."

"My students really enjoyed the challenge even though they found it difficult. Many thanks to RSC for organising this and for their continued support to chemistry education."

"[the candidate] was very surprised at how hard the exam was and very pleased that he had practiced some of the skills needed as he will be taking his AS in chemistry next year and has already been working through "Chemistry in context" in preparation."

"After goodness knows how many GCSE papers they've sat in the last few weeks, they said they'd enjoyed the experience!"

"The (A grade) student was very confident, but was shocked by the level of difficulty! Please let us know if you run this again,"

"All your hard work is very much appreciated. (Probably not by my students who did find it ...challenging. Could the clue have been in the name of the paper?)."

"She enjoyed the challenge - but found many areas she couldn't really attempt, as a Core + Additional Science student."

"The pupils all said that they enjoyed it!"

"Both my candidates enjoyed it immensely"

"My feeling is that this is a great idea which I would love to see developed"

"Our students enjoyed and appreciated this challenge and were not worried about having to finish on paper only. It is good to have a competition from RSC for this age group."

"All three students found the challenge enjoyable but very difficult."

"Thanks for the experience, the students enjoyed it!"

"Our students have only done the core and additional chemistry components so they found this exam very challenging."

"Thanks for the experience and looking forward to the results. "

"The examination is 'do able' in most parts. Questions B14, B21, B27 and B30 are not on the N. Ireland specification (syllabus). Some of the other questions are of AS standard."

"12 of the 14 girls were year 10 so some had not seen a chemical calculation at all and others only started on the basics."

"I thought that the content of the test was more AS level than GCSE."

"I look forward to the feedback from this exercise!"

And finally, the Head Teacher of Henrietta Barnett School was quoted in the *Evening Standard* after the 2008 GCSE results:

"Pupils quickly become 'bored' by lessons that focus on coaching them to pass tests…

GCSE is a difficult qualification. It probably has less subject content than it once did and it probably teaches less of the higher order thinking skills than before."

Appendix F – List of Participating Schools

Abbey Christian Brothers GS, Acklam Grange School, Adams Grammar School, Alcester Grammar School, Aldworth Science College, Altrincham Grammar School for Girls, Alva Academy, Ampleforth College, Ardingly College, Aylsham High School, Babington Community Technology College, Bablake School, Ballymena Academy, Balshaws CE High School, Banff Academy, Battle Abbey School, Bedford School, Beech House School, Belfast Royal Academy, Bell Baxter High School, Berry Hill High School, Bicester Community College, Biddulph High School, Bilton School, Birches Head High School, Bishop Challoner RC School, Bishop David Brown School, Bishop Luffa CE School, Bishop Rawstorne CE Bish Lan College , Bishop Veseys Grammar School, Bishopston Comprehensive School, Blackwood Comprehensive School, Bolton School Boys Division, Boston Spa School, Bordesley Green Girls School, Bosworth Community College, Bourne Grammar School, Bramhall High School, Bridge of Don Academy, Brighton & Hove High School, Broadgreen High School, Bryanston School, Brynteg Comprehensive School, Bury St Edmunds Upper School, Campbeltown Grammar School, Canford School, Carisbrooke High School, Cator Park School for Girls, Challney High School for Boys, Challney High School for Girls, Chapel en le Frith High School, Chatham Grammar School for Boys, Chatham Grammar School for Girls, Cheltenham Ladies College , City of London Freemens School, Claremont Fan Court School, Claremont High School, Cleeve School, Clyst Vale Community College, Cokethorpe School, Colchester County High School, Colchester Royal Grammar School, Coltness High School, Colyton Grammar School, Combe Bank School, Coopers Company & Coborn School, Court Moor School, Cranford Community College, Cromwell Community College, Cwmcarn High School, Dalriada School, Danetre School, Darwen Moorland High School, Davison CE High School for Girls, Dixie Grammar School, Dominican College, Down High School, Dr Challoners High School, Dukeries Community College, Dunfermline High School, Eaton Bank School, Edgbaston High School for Girls, Edmonton County Upper School, Ellesmere Port Catholic High School, Emerson Park School, Ermysteds Grammar School, Estover Community College, Exeter School, Farlingaye High School, Farlington School, Ffynone House School, Foyle & Londonderry College, Friesland School, Frogmore Community College, Fyndoune Community College, Garth Hill College, George Abbot School, Glenalmond College, Glyncoed Comprehensive School, Gravesend Grammar School, Great Baddow High School, Great Sankey High School, Greenhead High School, Haberdashers Monmth School for Girls, Hall Cross School, Hampton School, Hautlieu School, Havelock Academy, Headlands School, Heckmondwike Grammar School, Heles School, Henry Cort Community School, Heolddu Comprehensive School, Heritage Community School, Herts And Essex High School, High School of Dundee, Highfields School, Highgate School, Highsted Grammar School, Hinchley Wood School, Hodge Hill Girls School, Holy Family RC School, Honywood School, Hope Valley College, Hurstpierpoint College Sen School, Hymers College, Idsall School, Ise Community College, Isleworth And Syon School For Boys, James Allens Girls School, John Hampden Grammar School, John O'Gaunt School, John Taylor High School, Kennet School, Kingdown Community School, King Edward VI Camp Hill School for Boys, King Edward VI Camp Hill School for Girls, King Edward VI Girls High School (Birmingham), King Edward VI Grammar School (Chelmsford), King Edward VI Grammar School (Louth), King Edward VII School, King Edwards School (Birmingham), King Henry VIII School (Coventry), Kings College School, Kings School (Gutersloh), Kings Wood School, Kinross High School, Kirkley High School, Lampeter Secondary School, Landau Forte College, Langdon School, Langleywood School, Lavington Comprehensive School, Lealands High School, Leicester High School For Girls, Little Ilford School, Llandrindod High School, Longford Community School, Loughborough Grammar School, Macmillan Academy, Magdalen College School, Manor College of Technology, Marple Hall School, Mayville High School, Merchant Taylors School for Girls, Merchiston Castle School, Methwold High School, Milford Haven School, Minsthorpe Community College, Monmouth School, Morriston Comprehensive School, Mount St Marys College, Neale Wade Community College, Newland School For Girls, Newstead Wood School for Girls, Northampton School for Boys, Notting Hill & Ealing High School, Nottingham High School, Oakfield School, Oakham School, Oasis Academy : Immingham, Ockbrook School, Oldbury Wells School, Oriel High School, Orleans Park School, Orwell High School, Ossett School, Oundle School, Our Ladys Grammar School, Oxford High School GDST, Painsley Catholic College, Palmers Green High School, Park House School, Park View Community School, Parkside Federation, Penglais Comprehensive School, Perth High School, Peterborough High School, Peterhead Academy, Pilton

Community College, Plymouth College, Poole Grammar School, Portora Royal School, Portsmouth Grammar Senior School, Purbrook Park School, Queen Elizabeths Boys School, Queen Elizabeths Grammar School (Ashbourne), Queen Elizabeths Hospital School, Queen Margarets School, Queen Marys School, Queens College (Taunton), Queens College London, Queens School (Watford), Ramsey Grammar School, Redden Court School, Reigate Grammar School, Ripon Grammar School, Riverston School, Robert Clack School, Roedean School, Rookwood School, Rosedale College, Royal Grammar School (Guildford), Royal Grammar School (High Wycombe), Royal High School Bath, Royal Masonic School for Girls, Ryburn Valley High School, Rydal Penrhos, Ryde School with Upper Chine, Sackville Community College, Sacred Heart Catholic College, Sacred Heart Grammar School, Sale Grammar School, Sanday School, Sandbach High School, Sandy Upper School & College, Selly Park Tech Collage for Girls, Shaftesbury School, Sheffield High School, Sherburn High School, Shotton Hall School, Shrewsbury School, Soham Village College, South Bromsgrove High School, St Albans High School for Girls, St Augustines School, St Bees School, St Bernards Catholic Grammar School, St Birinus School, St Boniface RC College, St Catherines College, St Christopher School, St Dominics High School, St Francis College, St Georges College, St Gerards School, St Gregory the Great School, St James RC High School, St Johns School & Community College, St Louis Grammar School, St Lukes High School, St Margarets School, St Marys College, St Nicholas Catholic High School, St Olaves Grammar School, St Patricks Academy, St Philomenas Catholic High School, St Thomas More Catholic College, St Wilfrids School, Stafford Grammar School, Stamford High School, States Education Grammar School Guernsey, Stonelaw High School, Stonar School, Stover School, Strabane Grammar School, Stradbroke Bus & Enterprise College, Strangford Integrated College, Stratford upon Avon High School, Streatham & Clapham High School, Sutton High School, Tapton School, Teesside Preparatory & High School, Teign School, Temple Moor High School, Thames Christian College, The Bulmershe School, The Catholic High School Chester, The Cotswold School, The Crypt School, The Gedling School, The Grange School (Aylesbury), The Grange School (Northwich), The Grove School (Market Drayton), The Gryphon School, The Hayesbrook School, The Hewett School, The John Bentley School, The John Hanson Community School, The John Warner School, The Kings High School for Girls, The Lady Eleanor Holles School, The Latymer School, The Manchester Grammar School, The Maynard School, The Minster College, The Nottingham Bluecoat School, The Plume School, The Priory LSST, The Royal Latin School, The Royal School Armagh, The Skinners School, The Thomas Hardye School, The Westgate School, The Whitby High School, The Woodroffe School, Thomas Bennett Community College, Thomas Clarkson Comm College, Thomas More School, Thomas Telford School, Thornhill College, Thurston Community College, Tibshelf Community School, Tiffin Girls School, Tomlinscote School & 6th Form College , Tonbridge Grammar School, Tonypandy Community College, Torquay Boys Grammar School, Trinity Catholic School, Trinity RC High School (Upper), Trinity School & Perform Arts College, Trinity School (Carlisle), Trinity School (Croydon), Truro School, Uckfield Community Technology College , University College School, Uplands Community Tech College, Ursuline High School, Valentines High School, Verulam School, Waddesdon C of E School, Waldegrave Girls School, Walton High School, Warden Park School, Warwick School, Watford Grammar School for Girls, Wellington College, Wellington School, West Monmouth Comprehensive School, Westfield Community School, Westholme School, Whitecross School, Whitgift Secondary School, Whitley Bay High School, Wilmington Grammar School for Boys, Wilmington Grammar School for Girls, Wilsons School, Windsor Girls School, Withington Girls School, Ysgol Brynhyfryd, Ysgol Dyffryn Taf, Ysgol Gyfun Aberaeron, Ysgol Gyfun Emlyn, Ysgol Y Gwendraeth

Appendix G – Contributors to this Report and Organisation of the Competition

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