ROYAL STATISTICAL SOCIETY

DATA | EVIDENCE | DECISIONS

ACME

Advisory Committee on Mathematics Education

Embedding Statistics at A level:

a report on statistical requirements and assessment across A level courses in Biology, Business, Chemistry, Geography, Psychology and Sociology

Forewords

Professor Philip England

Chair of the Advisory Committee on Mathematics Education (ACME)

The UK economy needs more people who are skilled in working with quantitative data. It is clear that a confident grasp of mathematical and statistical approaches to data is key to making sense of the quantitative information that increasingly pervades our daily lives. These skills are needed in a wide range of disciplines, in the sciences, social sciences and, increasingly, in the humanities.

For many years ACME has highlighted the importance of increasing the number of learners studying mathematics post-16, and ACME particularly welcomes the increased emphasis, in recent A level reforms, on mathematical and statistical skills and quantitative methods.

I am very pleased that the RSS and ACME have collaborated on this work. The report makes constructive recommendations to policy makers, which are aimed at improving the overall quality of the assessment of statistical work across a broad spectrum of disciplines.

Professor Peter Diggle

President of the Royal Statistical Society (RSS)

In this data-rich world, there is no doubt that young people increasingly need to use and understand numerical data. The Royal Statistical Society takes an active interest in the use of numbers and statistics throughout education, as a key to understanding the world.

Although statistics as a discipline has its roots in mathematics, there are substantial requirements for statistics across the whole curriculum. These requirements need to be well informed. Over the last few years the Society has made significant efforts to improve the position of statistics inside and outside the mathematics curriculum. Subject specialists and their pupils need statistics as a comprehensive discipline to solve problems using data, and we are keen to support them in this.

In light of this, I very much welcome the recommendations in this report, and encourage policy makers and the wider education community to recognise their importance and act upon them.

Overview of the project

The **Royal Statistical Society** and the **Advisory Committee on Mathematics Education** collaborated on this project in recognition that statistics is increasingly important for a range of subjects for the 14–19 age group, in further and higher education and in employment. All young people need to develop statistical literacy in order to appreciate both the power and limitations of statistics in a range of general and specialist contexts. Statistical techniques are powerful tools which can enhance learners' understanding of subject content within a range of disciplines.

This report presents findings from an analysis of statistics in some recently reformed A levels in England. The aim was to investigate whether these reforms will result in the hoped-for improvements in the assessment of statistical skills.

Important issues emerged about the quality of statistical assessment, how to ensure that statistical skills are embedded in qualifications and how best to deliver coherent reforms. The report also sets out a range of areas that would benefit from further research.

A Introduction

In an increasingly data-rich world, there is a growing consensus that young people should leave school or college able to understand, analyse and critique data in their lives: as learners, as employees and as citizens.[1] The quantitative demands of university courses are increasing,[2] yet many learners arrive underprepared for those courses.[3] Many jobs now require problem solving skills and greater competence and confidence in using data.[4] Understanding statistical methods and approaches is crucial for informed analysis in many contexts.

The ongoing reforms of national qualifications aim to address these needs in two ways:

1 By increasing post-16 participation in mathematics and statistics courses;

2 By embedding mathematics and statistics within a range of A levels subjects.

This report investigates the effectiveness of embedding[5] quantitative skills in new A level qualifications, with a particular emphasis on statistics. Some of the reformed qualifications[6] were reviewed to consider how they assess statistics and how this might impact on teaching and learning and to identify areas requiring further attention.

Previous studies undertaken by SCORE and the Nuffield Foundation found that when no clear mathematical and statistical assessment requirements were set out, learners following the same courses of study had very different learning experiences.[7] Examination papers often allowed learners to opt out of doing quantitative elements.

The Department for Education has specified a proportion of marks for the assessment of these skills in some of the new A levels. This approach recognises that if mathematical and statistical skills are not assessed they may not be embedded in classroom teaching and learning. The six A level subjects reviewed in the current work (Biology, Business, Chemistry, Geography, Psychology and Sociology) have always required mathematical and statistical skills. The increased statistical elements of the reformed A level courses is to be welcomed.

This report considers the appropriateness and authenticity of statistics in six of the newly reformed A levels, as well as the coherence of statistical assessment within and between subjects. It builds on earlier work by the RSS that detailed the kinds of statistical learning that could be experienced across a range of subjects.[8] Improving how statistical content is assessed should contribute to the deepening of a learner's knowledge of the subject being studied and better development of their statistical literacy.

The importance of statistics is set out in **Box 1**. The emphasis on the different themes in Box 1 varies between subjects.

BOX 1 – Statistics across subjects

Statistics forms a valuable part of learning across a wide range of subjects, improving learners' understanding and enhancing their experience in the following ways:

- Statistics underpins investigational work which, in many subjects, involves activities that make up the Statistics Cycle:
  - Problem analysis: the formation of hypotheses and the design of surveys or experiments to test them;
  - Data collection and sampling;
  - Cleaning data;
  - Summarising and presenting data, using suitable displays and measures;
  - Analysing and interpreting data, using techniques which typically include estimation and null hypothesis testing.

- Statistics provides insight through visual display.

- Statistics provides a source of evidence, often involving the use of large, realistic data sets.

- Statistics provides inputs for mathematical models. Many subjects use mathematical models, often with inputs derived from data.

- Statistics deals with uncertainty. Two sources of uncertainty are commonly encountered:
  - Natural variability in an underlying population;
  - Experimental error, such as for example inaccurate measurements.

B The new 14 - 19 qualifications landscape

There has been a great deal of reform across the qualifications landscape for the 14-19 age group. Many reformed A levels will be introduced for first teaching in 2015 (and first assessment in 2017) and many GCSEs introduced for first teaching in 2016, with first assessment in 2018. Mathematics is being reformed to a different timetable to all other subjects.[9]

TABLE 1	14-19 qualifications reform timetable (selected qualifications)		
First teaching	**2015**	**2016**	**2017**
First assessment	**2017**	**2018**	**2019**
GCSE	Mathematics English	All other subjects	
A level	Biology Chemistry Business Psychology Sociology	Geography	Mathematics Further Mathematics

At A level, the reforms for many subjects involved the specification of mathematical or quantitative requirements **(see Table 1)**. This reflects a commitment by the Department for Education to embed the acquisition of mathematical and statistical skills across a range of subjects. There has also been substantial reform to mathematics qualifications, which will have an impact on the learning pathways for all 14 – 19 year olds.

- Starting from 2015, **GCSE Mathematics** will have more content than the previous GCSE and have a greater emphasis on problem solving.

- The new **A level Mathematics** will be introduced for first teaching in 2017. It will require all learners to study statistics and will also involve more problem solving and modelling.[10]

- **Core Maths** qualifications were introduced in over 150 'early adopter' schools and colleges in 2014 and will be taken more widely from September 2015. These are Level 3 qualifications.[11]

Subject requirements

In the new Department for Education specifications[12] it is stipulated that a minimum of 10% of A level Biology, Psychology and Business assessments include Level 2 mathematical skills.[13] The corresponding figure for Chemistry is 20%. For Sociology and Geography an analogous percentage is not specified, but lists of quantitative requirements are set out in the specifications.

These mathematical requirements do not distinguish mathematics and statistics so the awarding organisations can fulfil the requirement in a variety of ways. **Box 2** summarises the statistical skills in the reviewed subjects.

In Biology, Psychology and Chemistry, the subject aims and objectives set out by the Department for Education[14] require learners to develop a deep appreciation of the skills, knowledge and understanding of scientific methods. Learners should 'develop competence and confidence in a variety of practical, mathematical and problem solving skills'.

The Business requirements state that learners should 'acquire a range of relevant business and generic skills, including decision making, problem solving, the challenging of assumptions and critical analysis' and also should 'apply numerical skills in a range of business contexts'.[15]

The percentage of mathematical content is not prescribed in Sociology. However learners should 'understand and evaluate sociological methodology and a range of research methods through active involvement in the research process'.[16]

Geography has no prescribed percentage of mathematical/statistical content. However, there is an expectation that learners should become 'confident and competent in selecting, using and evaluating a range of quantitative and qualitative skills and approaches (including observing, collecting and analysing geo-located data) and applying them as an integral part of their studies'.[17]

BOX 2 – Statistical skills in selected A levels

Biology
Various statistical skills are listed under 'mathematical skills'. These include learners selecting and using a statistical test, and identifying uncertainties in measurements using simple techniques to determine uncertainty when data are combined.

Business
'Quantitative skills in business' list broad competencies, including using and interpreting quantitative information in order to make decisions.

Chemistry
Some statistical skills are listed under 'mathematical skills'. These include identifying uncertainties in data using simple techniques.

Geography
'Geographical skills' developed throughout the course are listed and include an equal balance of quantitative and qualitative methods and skills. The skills listed are comprehensive, including collecting, analysing and interpreting data and demonstrating skills in descriptive, inferential and relational statistics.

Psychology
Extensive statistical skills are listed under 'mathematical skills', including selecting and using a statistical test, using statistical tables to determine significance, and understanding the different between qualitative and quantitative data.

Sociology
The guidance is broad, with statistical skills listed under 'skills'. Learners must collect, record, interpret and evaluate 'evidence', which is understood to include both qualitative and quantitative data.

C The review process

The review was based on an exploratory analysis of:

- Department for Education and Ofqual subject requirements;
- Awarding organisations' specifications and sample assessment materials and mark schemes for the reformed qualifications.

Whilst subject requirements set out clear curriculum expectations, it is the sample assessment materials that provide the strongest indication of how assessment will work in live papers and therefore of how classroom teaching and learning might develop as a result.

In the case of Geography, the timing of the review meant that while Department for Education and Ofqual documentation was available, accredited sample assessment materials were not. Consequently both pre-reform sample assessment materials as well as those subsequently submitted for accreditation (in May 2015), were considered in the review.

For each of the subjects under review, specifications and sample assessment material from two awarding organisations were selected. These selections were sometimes determined by which qualifications had been accredited at the time of review. Overall the sample was fairly distributed across the six subjects and across

awarding organisations. The aim was not to distinguish between awarding organisations but rather to identify themes that were common within and between the six subjects.

The analysis was exploratory in nature and sought to identify key issues without any prejudice regarding the presence or nature of any such issues. In some cases minor issues appeared in isolation. Of greater interest were any patterns or collections of related issues. As the analysis proceeded, emerging findings were synthesised and refined and these are discussed below. The analysis drew on the expertise of those undertaking the work and subsequent input from key stakeholders.

Stakeholder engagement

Following the analysis and first-phase development of findings, a half-day event with key stakeholders was held in January 2015 which contributed to the development of the review findings. Stakeholders included policy experts and representatives from awarding organisations, the Department for Education and learned societies.

Initial observations and emerging recommendations were presented and informative feedback was received from subject specialists on the place and nature of statistics in their disciplines.

D Findings

The findings set out in sections **(I)** and **(II)** below are based on the review of documentation. The supplementary observation **(III)** is based on views repeatedly expressed at the stakeholder event.

(I) High-quality assessment

Given that high stakes assessments strongly influence classroom practice, the quality of statistical assessment is very important.

The review highlighted the need for:

i. **authentic statistics assessment** that uses realistic situations within questions;

ii. **embedded statistics** that deepens learners' knowledge and understanding of the use of data as part of the discipline;

iii. **appropriate use of statistics** within the subject context;

iv. statistics to be **examined at an appropriate level**.

The preparation of examination questions requires expertise in subject content and in statistics. The increased statistical elements of the A levels reviewed here presents a particular challenge for awarding organisations and those writing examination questions. The speed with which recent reforms were introduced allowed limited time for awarding organisations to gather and develop this expertise. Engagement with a range of stakeholders, including the relevant subject communities, is vital to ensure that statistical assessment is of high quality.

Authentic statistics assessment

Some assessment items that were reviewed presented learners with realistic experiences of working with data. In one particularly rich example learners were required to synthesise data from a variety of sources (e.g. in text, data, diagram and tabular forms) before drawing conclusions. However, other questions were arguably less authentic, for example, having very small sample sizes.

Questions with statistical content should, whenever possible, use realistic scenarios, with the statistical element integrated into the context (see below). Assessments should enable learners to demonstrate familiarity with the statistical cycle: data collection, presentation, analysis and interpretation **(see Box 1)**.

Embedded statistics

Assessments should enable learners to demonstrate their competence in making data-informed decisions that draw upon both their statistical knowledge and their subject learning.

Some sample assessment materials included questions in which learners were asked only to identify the statistical methods or tests to be used, without being asked to apply them. While such questions require statistical awareness, they will not help learners to develop competence and confidence in applying statistical methods or interpreting results. Furthermore they will not persuade learners of the value of statistical literacy for building subject knowledge.

The assessment materials also included instances where the statistical content formed an isolated part of the question, rather than being embedded within a meaningful context. For example, some questions required the calculation of a statistical measure, but this was not followed up by supplementary questions regarding its interpretation within the wider question scenario.

Appropriate use of statistics

The use of statistics will differ in practice across disciplines, depending on the nature of the analyses required and how the subject has evolved. This is to be expected. However, it is still important that the statistics are being used appropriately. Some examination questions reviewed showed statistical errors or inconsistencies, which is not acceptable. The identification and elimination of such errors requires specialist knowledge and expertise.

The review also highlighted that the statistical content of questions in some sample assessment materials were not depicting a realistic representation of what would be encountered in practice. For example, in some cases learners were asked to interpret data directly from a table when in a real-life situation it would be more helpful to draw a graph to understand the data more fully. Omitting the graph-drawing step makes inaccurate analysis more likely.

Level of statistical content

The review of sample assessment materials raised questions about whether statistical skills are consistently being assessed at the appropriate level. There were, for example, instances where learners were asked to find a certain percentage of a number or draw a bar graph from tabular data. While such elementary work may be appropriate in the context, questions that require mathematical skills below Level 2 must be in addition to stipulated Department for Education mathematical or quantitative requirements for that A level qualification.

There is a risk that learners will not gain an authentic, embedded experience of statistics at the appropriate level if awarding organisations minimise the demand of these elements. It may be that more explicit requirements are needed that apply to the demonstration of particular statistical skills.

(II) Coherence

In order to develop statistical literacy more fully, learners should have a sufficiently coherent statistical learning experience within and across subjects and between phases of their education.

Between GCSE Mathematics and A levels

The aim, over time, should be that the statistics learned at A level should be an integral part of the learning within that subject, and that it should build on prior statistical learning. When studying subjects at A level, learners should have the opportunity to apply knowledge gained in GCSE Mathematics. However, not all teachers of A level subjects may have an up-to-date awareness of the current content of GCSE Mathematics, in particular the statistics covered, or the competence of learners with particular GCSE grades.

Between subjects

Learners will encounter and use terms and approaches to statistics that are specific to the discipline being studied. This is entirely appropriate and is an essential part of a learner's development within a given subject area. However, to make the most of their statistical learning, learners also need to be able to transfer and apply their knowledge, skills and understanding between subjects. Whilst assumptions are sometimes made about the commonality and transferability of mathematics and statistics between subjects, in reality, the perceptions and experiences of learners can be quite different. Knowledge transfer is notoriously difficult to achieve.

Between Core Maths and A levels

Core Maths qualifications will have a high statistical content and they may well be taught by teachers from a range of subject specialisms. Many learners who take A level Psychology, Geography, Biology, Business and Sociology could soon also be taking Core Maths. These new qualifications offer the potential to create more coherent links between the statistics encountered in various A levels.[18] As with the new GCSE Mathematics, there is a need to increase teachers' awareness of these new qualifications and their content.

There is a potential opportunity to build on new Core Maths qualifications as they could play a bridging role between mathematics, statistics and other subjects. It may be that in the future the Core Maths teacher would have a role in helping learners understand the quantitative elements of their other subjects.

Coherence of reform processes

The final aspect of coherence relates to the wider process of curriculum and assessment reform. Many elements of this process have a direct impact on mathematics and statistics learning for the 14–19 age group, given that mathematics and statistics will be taught and assessed across A level curricula.

There has been an overhaul of pre- and post-16 qualifications. However, there have been some issues with the coordination of the reforms, between phases and also across subjects. Different groups and individuals have been involved in the reforms within and across subjects, with insufficient coordination and over multiple timescales. This might result in less than ideal statistics learning and assessment and could have a detrimental effect on the skills of learners. Lessons should be learned for the future if policymakers and others want to develop a world-leading assessment system.

(III) Supplementary observation

While originally the intention of the review was to focus on the documentation associated with reformed qualifications, the strong messages which came forward during the stakeholder event should also be taken into consideration. Whilst acknowledging the value of improving the assessment of statistical skills in subjects, many of the attendees highlighted the urgent need for investment in teacher professional development to support this reform agenda. Attendees repeatedly reiterated the point that many teachers lack the confidence and skills required for teaching the statistical elements of their courses.

E Recommendations

Assuring the high-quality assessment of statistical skills requires action on several fronts. Without this, it is likely that a laudable goal of assessment reform, that is the embedding of authentic statistical assessment in subjects, will not be fully realised.[19]

1. In addition to the subject specifications, the Department for Education should provide additional guidance on the new mathematical and statistical requirements of A level subjects so that in future examinations

   a. the assessment of statistics is authentic and at the appropriate level;

   b. requirements are applied consistently across awarding organisations.

2. Awarding organisations should be required to establish robust quality assurance processes for the mathematical and statistical strands of live papers. These should guarantee that the statistical content is authentic, embedded, appropriate, accurate and examined at the correct level. Within-subject and between-subject scrutiny should also take place to ensure consistency and high quality. Examiners should be supported to develop expertise in setting high-quality statistics questions.

3. The Department for Education should undertake or commission a formal review of the implementation of the recently reformed A levels. This should scrutinise the statistical (and mathematical) elements of live papers within and between subjects to investigate coherence. Papers involving statistical work should be analysed for statistical authenticity and embedding as well as the appropriate use of statistics at the required level. If necessary, appropriate interventions should be made.

4. Ofqual should ensure that future accreditation panels, and any review processes, include subject specialists with sufficient statistical expertise. Information on the selection process and criteria for expertise should be openly available. Furthermore Ofqual should commission additional statistical advice from experts to carry out independent assessments within subjects and across subjects in order to ensure consistency, authenticity and embeddedness of statistics.

5. Given the increased emphasis on statistical elements in examinations, Ofqual and the awarding organisations should undertake research and development on

   a. the effectiveness of different question styles and modes of assessment;

   b. how a more authentic experience of working with data could be incorporated into qualifications and their assessment e.g. by incorporating the use of technology. Such studies should explore the opportunities for cross-disciplinary learning.

6. The professional development of teachers needs to be understood and addressed:

   a. The Department for Education should commission a large-scale survey to investigate workforce capacity, competence and confidence in relation to the teaching of statistics in A level across the disciplines. This could also identify where targeted programmes of professional development are needed.[20]

   b. Learned societies, professional bodies and subject associations should ensure that support is made available for those teaching statistics within their subject areas. This support should address the teaching of statistics within the subject while also emphasising the transferability of statistical skills across subject boundaries. Schools and colleges should be encouraged to invest in professional development for teachers delivering statistical content in the new A level qualifications.

F Future work

There is broad agreement that improving the nation's quantitative skills is vital. More work is needed to ensure that the statistical skills that learners acquire at school/college are an adequate preparation for future study, employment and citizenship.

This review of statistics in some newly reformed A level subjects is a first step towards understanding the place of a wider range of quantitative and mathematical skills in the emerging 14-19 qualifications landscape. In addition to the recommendations above, the review has highlighted a number of related areas that require further attention.

(I) Mathematical content of 14–19 qualifications

This review considers the statistics in a number of reformed A levels. There would be value in carrying out a broader analysis of the mathematical and quantitative requirements in all A levels in order to understand how best to ensure that mathematical skills are embedded in learning, teaching and assessment.

This work could be extended to look at the wider 14-19 landscape. This large-scale study would involve looking at GCSE, Core Maths and A level specifications in depth, looking at both statistics in mathematics courses and qualifications, as well as looking at the place of statistics in a range of other subjects. It would benefit from a joined-up approach, where education researchers work closely with subject communities, Government and its agencies, as well as awarding organisations.

(II) Impact of Core Maths

A study monitoring the impact of Core Maths on the learning, teaching and assessment of statistics in non-mathematics A levels would be valuable. This could explore the extent to which Core Maths is improving the quantitative skills of learners who are working towards those A levels.

(III) Learners' experiences of, and attitudes to, learning statistics

A research study is needed to understand perceptions in schools and colleges about the learning, teaching and assessment of statistics. This could be designed to interview learners and teachers in schools and colleges.

It would also be illuminating to look at the various routes that learners take through their education, considering what statistics they encounter and the skills and experience gained during compulsory education.

G Endnotes and references

1. Prime Minister's Office (2014), 'Maths and science must be the top priority in our schools, says Prime Minister', 8 December 2014. British Academy (2012), *Society Counts*, A British Academy Position Statement.

2. Hodgen, J., McAlinden, M. & Tomei, A.(2014), Mathematical transitions: a report on the mathematical and statistical needs of students undertaking undergraduate studies in various disciplines, The Higher Education Academy.

3. Advisory Committee on Mathematics Education (ACME) (2011), *Mathematical Needs: Mathematics in the workplace and in Higher Education*.

4. CBI (2010), *Making it all add up: Business priorities for numeracy and maths*.

5. When the term embedding is used here it refers to the requirements that the Department for Education has set out in reformed A level specifications for the assessment of mathematical, statistical and quantitative skills. The report highlights throughout that embedding statistics in A level subjects should deepen learners' knowledge and understanding of the use of data as part of the discipline being studied.

6. Biology, Business, Chemistry, Geography, Psychology and Sociology. The subjects were chosen because of their potentially high statistical content. The first assessments of these A level qualifications will take place in 2017, with the exception of Geography, which has been deferred until 2018.

7. Nuffield Foundation (2012), *Mathematics in A level assessment: A report on the mathematical content of A level assessments in Business Studies, Computing, Economics, Geography, Psychology and Sociology*. SCORE (2012), *Mathematics within A level Science 2010 Examinations*.

8. Porkess, R. & Dudzic, S. (2013), *A world full of data: Statistics opportunities across A-level subjects*, RSS & IFoA; Porkess, R. (2011), *The Future of Statistics in our Schools and Colleges*, RSS & The Actuarial Profession.

9. Ofqual, 'Timeline of changes to GCSEs, AS and A levels', 24 November 2015.

10. It may be that there is a need to undertake an analysis of the A level Mathematics and Further Mathematics in due course.

11. Core Maths is a new suite of Level 3 qualifications for students with a grade C or above in GCSE Mathematics who do not take AS/A level Mathematics. Core Maths has been designed to allow students who choose not to take AS or A level mathematics to continue doing Mathematics post 16. These qualifications should allow students to develop problem solving and modelling skills. Department for Education (2014), Core maths qualifications: technical guidance.

12. Department for Education (2015), GCE AS and A level subject content, https://www.gov.uk/government/collections/new-a-level-and-as-level-qualifications-requirements-and-guidance (accessed 25 June 2015).

13. Level 2 refers to GCSE Mathematics Grade C (new GCSE Grade 4/5).

14. Department for Education (2015), GCE AS and A level subject content.

15. Ibid.

16. Ibid.

17. Ibid.

18. Expert Panel on Core Mathematics (2013), *Report from the expert panel on core mathematics*.

19. Some of the following recommendations seek to address the current situation, while others focus on improving the assessment process for the future.

20. ACME made a similar recommendation about the requirement for a comprehensive cross-phase analysis of the mathematical needs, mathematics subject knowledge and pedagogical content knowledge of all those who teach mathematics and of the capacity to meet those needs, ACME (2013), *Empowering teachers: success for learners*.

Acknowledgements

ROYAL STATISTICAL SOCIETY
DATA | EVIDENCE | DECISIONS

ACME
Advisory Committee on Mathematics Education