The Mathematical Backgrounds Of Undergraduates From England

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ABSTRACT

Participation in any kind of mathematical study during upper secondary education in England is significantly lower than in other educational systems. As a result, many English students enter university at age 18 or 19 having not studied mathematics for two years or more and relatively large proportions of students entering numerate degree programmes do not have a qualification in advanced school mathematics. To date, the mathematical preparation of those university entrants who do not have an advanced school mathematics qualification has not been documented. This study addressed this by analysing a large dataset formed from the combination of two large national databases in England: the National Pupil Database (NPD) and the Higher Education Statistical Agency (HESA) Database (N=253,557). This dataset provided the school mathematics qualifications of undergraduates from England across all degree subjects, who took GCSE Mathematics in 2008 and entered a UK university between 2010 and 2012. The study found that approximately 10% of undergraduates did not have a C grade at GCSE Mathematics, which is commonly assumed to be a minimum requirement for entry to university. In general, degree subjects with more mathematical demand recruited students with stronger mathematical backgrounds: 64% of undergraduates in subjects with high mathematical demand had an advanced school mathematics qualification compared to 24% in subjects with medium mathematical demand and 12% in subjects with low mathematical demand. For some university subjects with high and medium mathematical demand, for example Electronic and Electrical Engineering, there were substantial proportions of students with weak school mathematics backgrounds. There was considerable variation across universities with undergraduates in the high status Russell Group institutions having stronger school mathematics qualifications within the same degree subject.

1. INTRODUCTION

Significant concerns have been expressed about the mathematical backgrounds of university entrants in England on STEM degree programmes (e.g., Advisory Committee on Mathematics Education, 2011, Walport et al., 2010, Roberts, 2002, Engineering Council, 2000, Koenig, 2011). More recently, the challenges of 'big data' and the demand for increasing quantitative skills in the workplace have extended these concerns to the social sciences and the humanities (British Academy, 2015, Mason et al., 2015, Harris et al., 2014). These issues are not unique to England (e.g., Committee on Science, 2012, Hanushek et al., 2015), but England faces a further problem in that participation in any kind of mathematical study during upper secondary education is low in comparison to other systems internationally (Hodgen et al., 2010).

Many English students enter university at age 18 or 19 having studied no mathematics for two or more years and, as a result, large numbers of students entering numerate degree programmes[1] do not have a qualification in advanced school mathematics (Hodgen et al., 2014). Research studies have examined the relationship between school mathematics and degree performance (Adkins and Noyes, 2017, Shulruf et al., 2008); how student entry mathematical competencies have declined over time (e.g., Lawson, 2003, Engineering Council, 2000); the extent to which the standards of school mathematics qualifications have been maintained over time (e.g., Coe, 2007, Coe, 2008, Jones et al., 2016); and student perceptions of the value of advanced school mathematics qualifications (Darlington and Bowyer, 2016, Bowyer and Darlington, 2017). However, to date, the mathematical preparation of those university entrants who do not have an advanced school mathematics qualification has not been documented. Since this group forms a large proportion of undergraduates in UK universities, developing an understanding of their mathematical preparation prior to higher education is important. In this paper, we address this gap by examining the performance of undergraduates from England across all disciplines in school mathematics, including the basic GCSE Mathematics qualification.

2. BACKGROUND

Mathematics is a compulsory subject in England to age 16. At this point, almost all students take the General Certificate of Secondary Education (GCSE) in Mathematics as well as a range of other subjects.[2] The content of GCSE Mathematics is broadly similar to 'general' secondary mathematics programmes in other countries. Until 2016, students could achieve grades from A*–G in each subject. Grades C and above are considered a 'good' grade and have a gatekeeping role as the minimum entry requirement to many professions, such as teaching or nursing.[3 4] At the age of 16, students specialise and there are a variety of academic and vocational pathways in upper secondary, or post-16, education. Students with five or more GCSEs typically continue on an academic pathway to study pre-university qualifications in upper secondary education. A-levels are the standard pre-university qualifications in England and most students study three subjects over the following 2 years, up to the age of 18, with some students taking an additional AS-level, roughly equivalent to 'half' a full A-level. In recent years, a more vocationally oriented qualification, the BTEC, has become a significant alternative university entrance qualification. In 2012/3, 17% of university entrants from England entered with only BTECs compared to 67% with only A-levels and 16% with a combination of A-levels and BTECs (HEFCE, 2015).[5]

In response to concerns about participation in mathematics the then Secretary of State for Education, Michael Gove, announced in 2011 the government's aspiration that "within a decade the vast majority of pupils are studying maths right through to the age of 18" (Gove, 2011). This has resulted in a slew of policy initiatives, including strengthening the mathematics content in other A-levels (SCORE, 2012, The Nuffield Foundation, 2012); a revised Mathematics National Curriculum (Brown, 2011); reform to qualifications (Ofqual, 2014, Ofqual, 2017); as well as a major official report on addressing the problem (Smith, 2017). (See Noyes and Adkins, 2016, for a discussion of the development of this policy.)

In 2014, the UK government introduced a requirement that all students who had not achieved a GCSE grade C in mathematics by the age of 16 should continue to study mathematics in upper secondary education. There is no equivalent requirement for those who have achieved grade C or better, although a new Level 3 qualification, Core Maths, has been introduced (Browne et al., 2013). Core Maths has been designed to address the gaps in mathematical background that this paper identifies and has the potential over time to bring about significant improvements. Take-up has been low so far, with only around 3,000 students taking the first examinations in 2016 and just over 5,000 students in 2017, but these are early days.

Of the 396,000 students who achieved a C grade or above in 2014, only 106,000 (around a quarter) had achieved an AS or better in mathematics two years later in 2016 (Department for Education, 2017a, Department for Education, 2015). Most schools require at least a GCSE grade B for A-level Mathematics and many require at least grade A (Matthews and Pepper, 2007, Lee et al., 2018). This is not the case for most other subjects and, as a result, progression onto A-level Mathematics is skewed towards higher attaining students. The majority of those attaining the highest grades at GCSE go on to study at least AS-level Mathematics; 85% of those with A* grade and 58% of those with A grade, while only 18% of grade B students and a mere 1% of grade C students proceed (Hillman, 2014). This contrasts with most other subjects where the proportion of students with GCSE grades B and C is higher..

These low levels of participation in mathematics have a knock-on effect on higher education especially on subjects that require some level of numeracy. Using university admissions data, Hodgen et al. (2014) investigated the proportions of undergraduates with A- or AS-level Mathematics in eight numerate degree subjects in 2013. (See Table 1.)

[INSERT TABLE 1 ABOUT HERE.]

Unsurprisingly, the most numerate subjects, Chemistry and Economics, had high proportions of students with at least AS-level Mathematics, although, in each subject, more than a quarter of students did not have this qualification. Of those studying Business and Management, Geography, Psychology and Sociology under a quarter had at least AS-level Mathematics. In addition, participation in advanced school mathematics was unevenly spread across universities with the Russell Group having greater participation (Hodgen et al., 2014, see also Rodiero and Sutch, 2013, Lee et al., 2017).

3. METHODOLOGY

This paper analyses a dataset formed from the combination of two bespoke extracts from large national databases: the National Pupil Database (NPD) and the Higher Education Statistical Agency (HESA) database.[6] The dataset tracks 253,557 English-domiciled students who:

- took their GCSEs at age 16 in 2008,
- took a level 3 qualification at some point between 2009 and 2011 and,
- entered university at some point between 2010 and 2012.

This represents 67% of the 376,142 students in our dataset who gained a Level 3 qualification at some point between 2008/9 and 2010/11 (i.e. around a third of these students did not progress on to university between 2010/11 and 2012/13).

3.1 The HESA and NPD datasets

The HESA database holds information on a substantial number of factors such as student demographics, higher education institution (HEI) attended, and four subject variables to capture both single and joint-honours students, including proportion of time spent studying each subject, mode and level of study, and degree classification.

We made use of the "Unique Pupil Reference Number" which is assigned to children when they enter school, to track individuals (even though our dataset was completely anonymised) from their Key Stage 4 (KS4, ages 14-16) institution and qualification outcomes through to our Key Stage 5 (KS5, ages 16-19) extract. This was then further linked to the HESA extract containing data on undergraduate students by the NPD team at the Department for Education.

3.2 Categorising subjects in higher education

HESA uses the Joint Academic Coding System (JACS) to categorise university subjects for statistical and planning purposes. Our analysis uses the JACS 2.0 and JACS 3.0 categories that were in place between 2010/11 and 2012/13, with some minor amendments to allow comparison (HESA, 2012).[7] Under this system, university subjects are aggregated into 140 Principal Subjects that are then further aggregated into 19 high-level Subject Groups.

For the purposes of this paper, we have classified the 19 JACS Subject Groups into three categories, which we have called High, Medium and Low demand subjects, based on an estimation of the mathematical demands of most of the subjects in those Groups. The *high demand* category consists of three Subject Groups for which an A or AS-level in mathematics is generally regarded as essential, and calculus is usually required: Engineering and Technology, Mathematical Sciences, and Physical Sciences. The *medium demand* category consists of ten Subject Groups for which the primary need is numeracy, statistics and the analysis and interpretation of data: Agriculture and Related Subjects, Architecture, Building and Planning, Biological Sciences, Business and Administrative Studies, Computer Science, Education, Medicine and Dentistry, Social Studies, Subjects Allied to Medicine, and Veterinary Science. The *low demand* category consists of six arts and humanities Subject Groups where mathematics is less frequently needed for the degree programme: Creative Arts and Design, Historical and Philosophical Studies, Languages, Law, Mass Communications and Documentation, and Combined/General subjects.

3.3 Data cleaning

We followed a data cleaning and processing strategy previously adopted in Adkins and Noyes (2016). We conducted all data cleaning and analyses in *R*. The original text data files provided by the DfE and HESA were at various stages of matching and these data files contain a substantial number of duplicate cases which needed to be addressed to provide as realistically accurate descriptive analyses as possible.

Our process was as follows. Our KS4 and KS5 data files were already matched by the DfE, and so we stripped out the school contextual variables from KS4 and KS5, keeping the student ID, qualification route, and all examination results for A-level, AS-level and GCSE. Next we merged all KS5 years from 2009, 2010, and 2011, and then recoded all grade data into point scores - 0-8 for GCSE, 0-5 for AS-level and 0-6 for A-level. In the case of duplicate cases, after recoding, we retained the case with highest grade point achieved and deleted the duplicates from the dataset.

HESA records were provided for all students for all years of study. There were a small number of duplicate cases where students had either transferred institution or changed degree course. The HESA dataset was straightforward to prepare. We merged the data frames and then recoded the course aim (the qualification to be obtained), Joint Academic Coding System (JACS subject) codes to create subject area and detailed subject categories, and finally the HE_UKPRN (institutional identification). After we had merged the HESA records with the prior qualification data we then duplicated records where students were enrolled on joint honours programmes and multiplied any numerical statistics generated by the proportion of time spent studying the subject.

We have 253,557 unique students in our dataset, but while the NPD and HESA datasets are high quality, there are missing data in our extract. Data on university subject classifications are missing for 38 students. Since this number would have a negligible effect on the overall proportions, these students were ignored in our analysis. Data on mathematics qualifications are missing from our NPD extract for 16560 students. Data on GCSE and A-level examination results in the NPD are supplied by examination boards. As a result, these missing data relate to students who have taken an alternative Level 2 qualification not recorded in the NPD, primarily the iGCSE, a qualification taken mainly by students in independent schools that is roughly equivalent to GCSE. We have treated these students as having a GCSE but not a Level 3 mathematics qualification, but the GCSE grade as missing.

3.4 Limitations

Our data extract includes grades for GCSE and A-level/AS-level Mathematics and a variable indicating each student's principal Level 3 route (A-level, BTEC, IB etc). We do not have records of students' actual BTEC qualifications. As a result, one limitation is that we do not have details of any Level 3 Mathematics taken by students as part of BTEC, vocational or Access to Higher Education qualifications.[8] In some cases, notably those wishing to study Engineering, these qualifications do contain some Level 3 Mathematics, including in some cases calculus.

Our focus is on English-domiciled students who were aged 16 in 2007/8. As a result, our analysis does not include students from Wales, Scotland or Northern Ireland, international students, EU students, mature students and other older students who were aged 16 prior to 2007/8.

For students on combined degrees, we follow the HESA 'full-time equivalent' (FTE) practice of apportioning students in proportion to the contribution of each separate subject (HESA, 2017). This approach avoids double-counting these students. As a result, our estimates will differ from actual headcount figures. In order to protect the anonymity of students and HEIs, we do not report data for a subject where an HEI has fewer than 5 FTE students in line with the NPD statistical disclosure control regulations.

Our dataset tracks a group of students who were age 16 in the academic year 2007/8. An alternative approach would be to focus on students who started university during a particular year (see, e.g., HEFCE, 2015) or on admissions data (Hodgen et al., 2014). Each of these approaches will produce slightly different estimates, particularly as there have been some changes to participation over time.

4. RESULTS

4.1 High, medium and low mathematical demand subjects

In Table 2, we present the mathematical backgrounds of students for degree subjects with high, medium and low mathematical demand, further broken down by the 19 high-level JACS Subject Groups.

[INSERT TABLE 2 ABOUT HERE]

Among the high demand Subject Groups there are a surprising number of students who do not have A or AS-level Mathematics: 40% in Engineering and Technology, and 47% in Physical Sciences. This constitutes more than 10,000 students. A relatively large number of students in Engineering and Technology (761, 6%) have not achieved a C grade at GCSE.

Across the medium demand Subject Group around three-quarters of entrants have no more than GCSE Mathematics, approximately 85,000 (62%) with a GCSE A*-C grade and a further 15,000 (11%) without the equivalent of a C grade or above at GCSE.

Taken overall, the distribution of mathematical backgrounds of students in the medium and low demand categories is remarkably similar with around a quarter of students having advanced school mathematics qualifications. Some of the medium demand subjects attract large numbers of students with A or AS-level qualifications in mathematics. For example Medicine and Dentistry (72%) and Veterinary Science (60%) both have equal or higher proportions than Engineering and Technology (60%) and Physical Sciences (53%). These are high status, competitive subjects, where A-level Mathematics is seen as a general marker of ability. The same 'signalling' effect (Adkins & Noyes, 2016) can be seen in some individual subjects in the low demand group. Some modern foreign language courses, for example, have around a quarter of students with an advanced school mathematics level qualification.[9]

There are high absolute numbers and proportions of students in some medium demand Subject Groups who have achieved only a C grade at GCSE: for example, Biological Sciences, 7,100 (23%); Business and Administrative Studies, 8,200 (27%); Education, 3,700 (36%); Social Studies, 5,500 (23%): Subjects Allied to Medicine, 4,200 (24%). There are also some medium demand Subject Groups where there are large numbers of students with GCSE grades D – G: for example Business and Administrative Studies, 3,600 (12%), Computer Science, 1,500 (15%) and Education, 1,500 (15%).

4.2 Variation at principal subject level

Our analysis indicates that there is considerable variation at Principal Subject level within the high-level Subject Groups. In the following section, we examine this variation within four Subject Groups to illustrate the range of this variation. We first discuss one Subject Group from the high demand area, Engineering and Technology. We then discuss three medium demand Subject Groups: Biological Sciences, Social Studies, and Business and Administrative Studies. These three Subject Groups together account for the majority of the students in the medium mathematical demand area (around 85,000, or just over 60%). Approximately 67,000, i.e. more than three quarters of this sub-group of medium demand students have not studied mathematics beyond GCSE.

For each of these subjects, we contrast the distributions of undergraduates' mathematical backgrounds for selected Principal Subjects. (See Figures 1, 2, 3 and 4.) These figures show the percentage of those with a post-16 mathematics qualification compared to those with at most a GCSE in mathematics, breaking this latter group down by GCSE grade attained.

Engineering and technology: Within the Engineering and Technology Subject Group, the three highest volume Principal Subjects (Mechanical, Electronic and Electrical, and Civil Engineering) account for just over 8000 students. (See Table 3.) This is around 59% of the Subject Group. There is a marked contrast between Mechanical and Civil Engineering on the one hand and Electronic and Electrical on the other. (See Figure 1), In Mechanical and Civil Engineering, 70% and 75%, respectively, had a post-16 mathematics qualification, respectively, while only 45% of Electronic and Electrical Engineering students have a post-16 mathematics qualification. Moreover, 9% of Electronic and Electrical Engineering students did not achieve a C grade in GCSE

Mathematics. Given the mathematical demands of the subject, this is on the face of things surprising. It is possible that some of these Electronic and Electrical Engineering students may have come through the BTEC route. In 2012/13 1950 students entering university had taken an Engineering and Technology BTEC.[10] These students would have studied some Level 3 mathematics. Others may have followed vocational pathways or taken Access to Higher Education courses, which could involve some Level 3 mathematics.[11]

[INSERT FIGURE 1 AND TABLE 3 ABOUT HERE.]

*Biological Sciences:*Three Principal Subjects (Biology[12], Psychology, and Sport and Exercise Science) account for all the students in the Biological Sciences Subject Group. (See Table 4.) The distribution charts (Figure 2) show that the profile of students across the three subjects is very different: The modal mathematics background for Biology students is a post-16 mathematics qualification, with 43% of students having A-level, AS-level or IB. In comparison only 15% of Psychology students and 8% of Sport Science students had A-level, AS-level or IB. Turning to GCSE Grades, the modal backgrounds for Psychology and Sport Science are GCSE Grade B and GCSE Grade C, respectively. We note, however, the importance of the BTEC qualification in Sport Science, a qualification which does contain a small amount of mathematics (mainly data and statistics) as part of the mandatory modules. HEFCE's analysis indicates that some 9570 English-domiciled non-mature students entering university in 2012/13 had a BTEC in Sport and Exercise Science (HEFCE, 2015).

[INSERT FIGURE 2 AND TABLE 4 ABOUT HERE.]

Social Studies: Within the Social Studies Subject Grouping, the three highest volume Principal Subjects (Economics, Politics and Sociology) account for nearly 17,000, or 68%, of the students in the Subject Group. (See Table 5). The distribution graphs (Figure 3) show the profile of students across the subjects. The modal mathematics background for Economics students is a post-16 mathematics qualification with 72% of students having A-level, AS-level or IB. In comparison, only 17% of Politics students and 6% of Sociology students have A-level, AS-level or IB, with the modal GCSE background being Grade B and Grade C, respectively.

An interesting comparison relates to Geography students, because those who study Human and Social Geography are included in the Social Studies Subject Grouping, whereas those who study Physical Geography are included within the Physical Sciences Subject Grouping. (See Figure 4 and Table 6.) We note with interest that the profile of the mathematical backgrounds of the cohort of Human and Social Geography students is very similar to that for Physical Geography, a subject with on the face of it a much higher mathematical demand.

[INSERT FIGURE 3, TABLE 5, FIGURE 4 AND TABLE 6 ABOUT HERE.]

Business and Administrative Studies: Within the Business and Administrative Studies Subject Grouping, the four highest volume Principal Subjects (Accounting, Business Studies, Hospitality and Management) account for around 24,500, or 82%, of the students in the Subject Group. (See Table 7.) As with the previous Principal Subjects, the profile of students across the subjects is very different. (See Figure 5.) The modal mathematics background for Accounting students is a post-16 mathematics qualification with 54% of students having A-level, AS-level or IB. In comparison, only 20% of Management students and 15% of Business Studies students have A-level, AS-level or IB, with the modal background being GCSE Grade B for Management (26%) and GCSE Grade C for Business Studies (30%).

[INSERT FIGURE 5 AND TABLE 7 ABOUT HERE.]

In this analysis, we report on the mathematical backgrounds of entrants in three of the ten high-level Subject Groups within the medium mathematical demand group of subjects and find considerable variation across subjects. This variation is repeated across all the ten principal Subject Groups. In some areas, like Economics, almost all entrants have an advanced school mathematics qualifications, whereas in others like Sociology, (some areas of which have similar mathematical demands to Economics), only a very small minority are so qualified.

4.3 Variation across institutions

In this section we analyse how the mathematical backgrounds of English-domiciled entrants vary across universities. The university sector is highly stratified in terms of entrance qualifications and we have chosen to use university mission groups as the basis for our analysis.

[INSERT TABLE 8 ABOUT HERE]

The university mission groups operate as lobby, or interest, groups for very broadly similar universities. There are currently three active mission groups: the Russell Group (a group of large research-intensive universities); the University Alliance (an association of technical and professional universities) and Million Plus (a group of more recently established universities). We also consider the 1994 Group, a now disbanded mission group of smaller research-intensive universities which was active during the period considered.[13] In addition, there are many non-aligned universities, with just over a third of the student cohort. (See Table 8.)

We note that the ranking of university departments can be different to the ranking of universities overall. We attempted to compare universities on the basis of the qualifications of their accepted applicants using data obtained from UCAS. However, many of the resultant groups were very small and the terms of the data access did not allow us to publish sufficient evidence to present a valid comparison of universities.

In Table 9, we present the mathematical backgrounds of students, for higher education Subject Groups with high, medium and low mathematical demand across the different mission groups.

[INSERT TABLE 9 ABOUT HERE]

This analysis indicates that:

- For subjects with high mathematical demand, the vast majority (84%) of Russell Group entrants have an advanced school mathematics background, but, in contrast, the majority (74%) of Million Plus entrants have no more than a GCSE in mathematics.
- For subjects with medium mathematical demand, greater than 80% of entrants to Univerisity Alliance, Million Plus and the non-aligned group have no more than a GCSE in mathematics, in comparison with 50% for Russell Group and 67% for ex-1994 univeristies.
- For subjects with low mathematical demand, the proportions of undergraduates without an advanced school mathematics qualification are much higher. Even for the Russell Group, only a quarter of undergraduates in

these Subject Groups have an advanced school mathematics qualification, and overall, across all universities, the proportion is only 12%.

In addition, the proportions of Million Plus students without a C grade at GCSE Mathematics are striking: 23% overall, and 14% for subjects with high mathematical demand.

We also note that the figures presented here differ slightly from Rodiero & Sutch's (2013) analysis, which reported higher proportions of entrants with mathematics A-level: 51% (Russell Group), 43% (ex-1994), 21% (University Alliance), 17% (Million Plus) and 19% (non-aligned). This is because Rodiero & Sutch's dataset excluded students with BTec qualifications who had not achieved at least one A-level, and other non-traditional routes to university. As a result, their analysis overestimates the proportions of all entrants who have a mathematics A-level.

4.4 Variation within subjects

In this section, we outline how the mathematical backgrounds of English-domiciled students in a number of single (Principal) subjects can vary between institutions. We have chosen four principal subjects that between them show the wide range of mathematical backgrounds that can exist, even within single subjects. We present the results for Electronic and Electrical Engineering and the principal subjects within the Biological Sciences high-level Subject Group (Biology[14], Psychology and Sport and Exercise Science), which have a high degree of variation in entrants' mathematical backgrounds.

For each subject we givea dotchart showing the percentage of entrants with a post-16 mathematics qualification to highlight the differences between institutions. Each dot represents an HEI. We have anonymised the HEIs, but have indicated which university mission group they are affiliated to, or in the case of the 1994 Group were previously affiliated to.[15] In addition, we present a boxplot showing the distribution of the proportions across all institutions. Note that outliers within the boxplot are cases that fall outside 1.5x the interquartile range.

Electronic and Electrical Engineering: As we have previously observed, the mathematics backgrounds of entrants to Electronic and Electrical Engineering are rather surprising, given that it is a mathematically demanding subject. Only 44% of all entrants have AS Mathematics or greater and 23% of all entrants had only achieved a C grade at GCSE Mathematics. Figure 6 shows the wide variation in the proportion of students with advanced school mathematics across the 55 institutions offering the subject. The contrast between top and bottom quartiles is marked. The 15 institutions with the mathematically highest attaining intake all had 80% or more of their student cohorts who hold at least AS Mathematics, and several institutions had close to 100%. In contrast, there are 17 institutions that had 30% or fewer of their students with AS Mathematics or more. However it seems likely that many of the students without a post-16 mathematics qualification would have studied some level 3 mathematics. This might be on a BTEC or a vocational pathway or the Access to Higher Education qualification. The majority of Electronic and Electrical Engineering courses accept the Access to Higher Education qualification and almost all specify that this must include some Level 3 mathematics, although the extent of the mathematics specified varies considerably.

[INSERT FIGURE 6 ABOUT HERE.]

Biology: Figure 7 shows the variation across the 89 institutions in Biology. The top 11 institutions with the mathematically highest attaining intake, all Russell Group institutions, each had greater than 60% of students with at least AS Mathematics with three institutions having greater than 80%. In contrast, there are 35 institutions that had fewer than 30% of students with AS Mathematics or more.

[INSERT FIGURE 7 ABOUT HERE.]

Psychology: Figure 8 shows the variation across the 111 institutions in Psychology. The seven institutions with the mathematically highest attaining intake, all Russell Group institutions, had greater than 40% of students with at least AS Mathematics. By contrast, the majority of institutions have fewer than 20% of students with AS Mathematics or more.

[INSERT FIGURE 8 ABOUT HERE.]

Sport Science: Figure 9 shows the variation across the 76 institutions in Sport Science. Two institutions had close to 40% of students with at least AS Mathematics.

By contrast, the majority of institutions had fewer than 20% of students with AS Mathematics or more. Moreover, although the range across institutions was smaller than for the other subjects that we consider, the boxplot of all institutions suggests that six institutions are outliers to the main distribution and attract a cohort of entrants of whom a greater proportion had an advanced school mathematics qualification.

[INSERT FIGURE 9 ABOUT HERE.]

We have reported the variation across universities in just one high-level Subject Group within the medium mathematical demand group but the variation is replicated across the subjects. In particular, for almost all subjects, there are a small group of universities, mainly from the Russell Group, who attract students with stronger mathematical backgrounds than the remainder of universities within the same principal subject.

5. DISCUSSION AND CONCLUSION

It is commonly assumed that all, or almost all, of English-domiciled entrants to UK universities have a minimum C grade at GCSE Mathematics, since most universities state this in their entrance criteria (Osmon, 2009). Our analysis shows that this is not the case. Approximately 25,000 entrants to university in our dataset (around 10%) had not achieved a C grade at GCSE Mathematics.

Moreover even in Engineering, a group of subjects with high mathematical demands, a significant proportion of students have relatively weak school mathematics qualifications. This is particularly noticeable in Electronic and Electrical Engineering, where the majority only had GCSE (55%), and of those the largest groups obtained a C grade (22%) or a grade B (17%), whilst almost 10% did not achieve a Grade C.

In addition, we have examined the variation across universities. Unsurprisingly, given the findings of our previous work (Hodgen et al., 2014), the higher status universities have a smaller proportion of students with weak school mathematics qualifications: only 6% of Russell Group entrants have at most a C grade compared to 33% across the university sector as a whole. In large part, this is likely to be a consequence of the “signalling effect” of achievement in mathematics as a marker of ability for some high status university subjects and for some high status universities (Noyes and Adkins, 2016).

We also compared the variation in the mathematical backgrounds of students across universities within subjects. This comparison showed considerable variation across institutions.

Taken together, these findings have considerable consequences for degree programmes across the university sector. As the British Academy (2015) has commented:

> UK universities suffer from a poverty of aspiration in relation to their students' quantitative skills. With undergraduates embarking on courses with varying, and often weak, fluency in statistics, many universities have modified degree courses in a non-quantitative direction. In some cases, these changes in course design reflect weaknesses in university teachers' own quantitative skills. Students often graduate with little confidence in applying what skills they do have, which then has knock-on effects for businesses as graduates can be ill-prepared for the data demands of the workplace. (p.10)

The findings also have serious consequences for particular degree programmes in subjects of medium mathematical demand and some subjects of high mathematical demand. Recent research suggests that the mathematical backgrounds of entrants do not appear to significantly affect degree outcomes in Biology and Chemistry (Adkins and Noyes, 2017). However, they are likely to affect the content and support offered by universities on such courses. Universities may offer additional mathematics support beyond the normal curriculum through mathematics support centres (Perkin et al., 2013) and some provide tailored mathematics courses specific to the subject. Whilst such courses can be successful (Heck and Van Gastel, 2006), this may restrict the content offered elsewhere due to time and resource constraints. And as the British Academy (British Academy, 2015) points out, many universities may choose to reduce the mathematical content of some of their degree programmes.

In his recent review of 16-18 mathematics education, Sir Adrian Smith (2017) concludes that, although the need is very pressing, the education system in England does not yet have sufficient teaching capacity or sufficient range of mathematical pathways. A key recommendation of the Smith Report is for government and the UK Learned Societies to encourage universities to provide better “signalling” of the importance of further study of mathematics to prospective students and to encourage schools and colleges to provide appropriate mathematics pathways. At the time of writing, there is little evidence of any significant change in this area beyond a few institutions encouraging the Core Maths qualification in their central admissions statements.[16] The evidence presented here suggests that this strategy should focus less on Russell Group institutions and more on the other mission groups or non-aligned institutions.

The results of our study provide further evidence of the need to increase participation in the study of mathematics by students aged 16 to 18 in England. The new Core Maths qualification offers a potential pathway and, indeed, may be more appropriate than a conventional A-level for many medium demand subjects (Browne et al., 2013). Our study shows that there are around 100,000 university entrants to degree programmes of medium and high demand who have at least a C in GCSE Mathematics but not A-level or AS Mathematics. Many of these students would benefit from Core Maths and this group of students is an obvious target for its expansion. However achieving this level of participation will be challenging given existing teacher shortages in mathematics (Advisory Committee on Mathematics Education, 2018, Allen and Sims, 2018).

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NOTES

1. By numerate degree programmes, we mean degree programmes in subjects that involve some mathematics and/or statistics (Advisory Committee on Mathematics Education, 2011).

2. In England, schools students take the General Certificate of Secondary Education (GCSE), usually at age 16.

3. In 2015/6, 97.3% of those in state-funded schools had taken GCSE Mathematics by age 16 (Department for Education, 2017b).

4. From 2017, a revised system of numbered grades was introduced. The boundary for the new Grade 4 is intended to be equivalent to the old Grade C.

5. A few students take alternative qualifications, although the numbers are small. For example, in 2016, 4755 students across the UK took the International Baccalaureate Diploma (IB), constituting less than 1% of the cohort in England (International Baccalaureate Organization, 2016).

6. The terms of our access agreement do not permit us to make our data extract publically available directly, although the original data can be obtained subject to various conditions regarding data security and confidentiality. The R code used for the analysis is available from the authors.

7. In addition, some categories with very small numbers of students were collapsed.

8. The Access to Higher Education Diploma is designed for those who left school without qualifications such as A-Levels but who would like to study in higher education

9. In French and German, for example, 23% and 27% of students, respectively, have A, AS or IB Mathematics.

10. A total of 1950 of the entire cohort of English-domiciled students entering university had an Engineering and technology BTEC (HEFCE, 2015): http://www.hefce.ac.uk/media/hefce/content/pubs/2015/201503/HEFE2015_03.pdf

11. In 2012/13, 5540 students on Access to Higher Education courses were aged 19 or under: http://www.accesstohe.ac.uk/AboutUs/Publications/Documents/AHE-Diploma-courses-students-14.PDF

12. The Biological Sciences principal subject group included several subjects with a relatively small number of undergraduates. Hence, for the purposes of this analysis, Biology is a combination of all other subjects within the Biological Sciences high-level Subject Group, including *inter alia* Botany, Genetics, Microbiology and Zoology.

13. For information on the university mission groups, see, for example: http://www.universitiesuk.ac.uk/linksforstudents/Pages/Anoverviewofthehighereducationsector.aspx

14. As previously, Biology is a combination of all other subjects within the Biological Sciences high-level Subject Group.

15. In addition, HEIs were excluded if the number of students entering a degree course in the subject was fewer than 10 in line with the terms of our data access agreement.

16. For example, Lee et al.'s (2017) analysis of 2017/18 data suggests that such signalling of a requirement for A-level Mathematics is largely confined to high mathematical demand subjects, and even then is not universal.

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	A-level	**AS-level only**	**AS-level or above**
Biology	38%	12%	50%
Business & Management	15%	6%	20%
Chemistry	71%	8%	79%
Computing related	43%	5%	48%
Economics	69%	6%	76%
Geography	20%	8%	28%
Psychology	13%	5%	18%
Sociology	4%	2%	6%

Table 1: The proportion of UK students entering university in 2013 with either A-level or AS-level Mathematics in selected degree subjects. Source: UCAS data. Rounding errors apply. Reproduced from Hodgen et al. (2014).

Demand Category and High-Level Subject Group	Number of Students	Highest School Mathematics Qualification A-level (or AS)	GCSE	A*	A	B	C	D-G	GCSE missing
High Mathematical Demand									
Engineering and Technology	13,711	60%	40%	0%	5%	14%	15%	6%	1%
Physical Sciences	13,385	53%	47%	2%	12%	18%	11%	2%	3%
Mathematics Sciences	6,080	97%	3%	1%	0%	1%	1%	0%	0%
Total (High Demand)	33,176	64%	36%	0%	7%	13%	10%	3%	2%
Medium Mathematical Demand									
Biological Sciences	31,274	22%	78%	2%	15%	27%	23%	8%	3%
Business and Administrative Studies	30,078	21%	79%	1%	9%	26%	27%	12%	3%
Social Studies	24,423	25%	75%	2%	12%	24%	23%	10%	5%
Subjects Allied to Medicine	17,560	26%	74%	2%	13%	22%	24%	11%	2%
Computer Science	10,418	25%	75%	0%	6%	22%	30%	15%	1%
Education	10,149	8%	92%	1%	9%	29%	36%	15%	1%
Architecture, Building and Planning	4,774	32%	68%	1%	9%	23%	23%	7%	4%
Medicine and Dentistry	4,552	72%	28%	10%	11%	2%	1%	1%	4%
Agriculture and Related Subjects	2,558	14%	86%	1%	13%	27%	29%	13%	4%
Veterinary Science	516	60%	40%	9%	17%	5%	3%	1%	6%
Total (Medium Demand)	136,302	24%	76%	2%	11%	24%	25%	11%	3%
Low Mathematical Demand									
Creative Arts and Design	32,643	8%	92%	2%	11%	27%	32%	18%	3%
Languages	17,812	15%	85%Ba	7%	21%	27%	17%	5%	8%
Historical and Philosophical Studies	12,901	19%	81%	5%	19%	26%	17%	4%	9%
Law	10,258	16%	84%	4%	16%	28%	23%	10%	3%
Mass Communications and Documentation	8,543	4%	96%	1%	9%	28%	37%	19%	2%
Combined/General Subject Unspecified	1,885	17%	83%	2%	13%	24%	26%	14%	4%
Total (Low Demand)	84,043	12%	88%	3%	15%	27%	26%	12%	5%
Total Overall	253,520	25%	75%	2%	12%	24%	23%	10%	4%

Table 2: Highest school mathematics qualification for students in high, medium and low demand degree subjects. Rounding errors apply.

Subject	N	Post-16 Maths	GCSE Only	A*	A	B	C	D-G	None/ Missing
Civil Engineering	2,053	75%	25%	0%	3%	9%	8%	3%	1%
Electronic and Electrical Engineering	2,557	45%	55%	0%	6%	17%	22%	9%	1%
Mechanical Engineering	3,486	70%	30%	0%	4%	11%	11%	3%	1%

Table 3: Highest school mathematics qualification for selected subjects within the Engineering Subject Group. Rounding errors apply.

Subject	N	Post-16 Maths	GCSE Only	A*	A	B	C	D-G	None/ Missing
Biology	9,839	43%	57%	4%	17%	19%	11%	3%	3%
Psychology	11,413	15%	85%	3%	18%	32%	23%	6%	3%
Sport and Exercise Science	10,022	8%	92%	1%	11%	29%	34%	15%	2%

Table 4: Highest school mathematics qualification for selected subjects within the Biological Sciences Subject Group. Rounding errors apply.

Subject	N	Post- 16 Maths	GCSE Only	A*	A	B	C	D-G	None/ Missing
Economics	5,405	72%	28%	1%	8%	11%	5%	1%	3%
Politics	4,741	17%	83%	4%	18%	28%	18%	5%	9%
Sociology	6,570	6%	94%	1%	10%	30%	36%	15%	4%

Table 5: Highest school mathematics qualification for selected subjects within the Social Studies Subject Group. Rounding errors apply.

Subject	N	Post- 16 Maths	GCSE Only	A*	A	B	C	D-G	None/ Missing
Human and Social Geography	2,438	24%	76%	6%	21%	26%	11%	1%	10%
Physical Geography	2,999	26%	74%	4%	20%	27%	14%	2%	6%

Table 6: Highest school mathematics within the two main routes in Geography degrees. Rounding errors apply.

Subject	N	Post-16 Maths	GCSE Only	A*	A	B	C	D-G	None/ Missing
Accounting	3,991	54%	46%	1%	9%	19%	13%	4%	1%
Business Studies	10,970	15%	85%	1%	10%	28%	30%	12%	4%
Hospitality, Leisure, Sport, Tourism and Transport	4,627	5%	95%	0%	6%	25%	39%	21%	3%
Management Studies	4,961	20%	80%	2%	13%	26%	23%	11%	5%

Table 7: Highest school mathematics qualification for selected subjects within the Business and Administrative Subject Group. Rounding errors apply.

Mission Group	Number of HEIs	Percentage of all HEIs	Total number of students	Total percentage of students
Russell Group	24	15%	61,580	24%
Ex-1994	10	6%	15,277	6%
University Alliance	18	11%	59,696	24%
Million Plus	18	11%	26,696	11%
Non-aligned	87	55%	90,271	36%
Overall	157	100%	253,520	100%

Table 8: A breakdown of the university mission groups at the time of the analysis. Figures are subject to rounding errors.

Demand Category and University Mission Group	Number of Students	Highest School Mathematics Qualification		A*	A	B	C	D-G	GCSE missing
		A-level (or AS)	GCSE						
High Mathematical Demand									
Russell Group	13,405	84%	16%	2%	6%	4%	1%	0%	2%
Ex-1994	2,565	75%	25%	2%	8%	9%	4%	0%	2%
University Alliance	7,209	45%	55%	1%	7%	21%	19%	5%	1%
Million Plus	1,858	26%	74%	0%	7%	24%	27%	14%	1%
Non-aligned	8,139	52%	48%	1%	7%	18%	16%	5%	1%
Total High Mathematical Demand	33,176	64%	36%	1%	7%	13%	10%	3%	2%
Medium Mathematical Demand									
Russell Group	28,544	50%	50%	6%	17%	14%	6%	2%	6%
Ex-1994	7,050	33%	67%	3%	18%	25%	13%	4%	3%
University Alliance	35,828	16%	84%	1%	10%	29%	31%	11%	2%
Million Plus	15,600	11%	89%	0%	6%	25%	35%	22%	1%
Non-aligned	49,279	18%	82%	1%	10%	27%	30%	13%	2%
Total Medium Mathematical Demand	136,301	24%	76%	2%	11%	24%	25%	11%	3%
Low Mathematical Demand									
Russell Group	19,630	24%	76%	10%	25%	19%	7%	1%	13%
Ex-1994	5,662	15%	85%	4%	22%	30%	18%	6%	6%
University Alliance	16,659	7%	93%	1%	11%	31%	33%	15%	2%
Million Plus	9,239	4%	96%	1%	7%	24%	36%	26%	2%
Non-aligned	32,853	9%	91%	1%	12%	29%	32%	14%	3%
Total Low Mathematical Demand	84,043	12%	88%	3%	15%	27%	26%	12%	5%
Overall									
Russell Group	61,580	49%	51%	6%	17%	14%	5%	1%	7%
Ex-1994	15,277	33%	67%	3%	18%	24%	13%	4%	4%

University Alliance	59,696	17%	83%	1%	10%	29%	30%	11%	2%
Million Plus	26,696	10%	90%	0%	6%	24%	35%	23%	2%
Non-aligned	90,271	17%	83%	1%	10%	27%	29%	12%	2%
Total	253,520	25%	75%	2%	12%	24%	23%	10%	4%

Table 9: Highest school mathematics qualification for students in high, medium and low demand subjects by university mission group. Rounding errors apply.

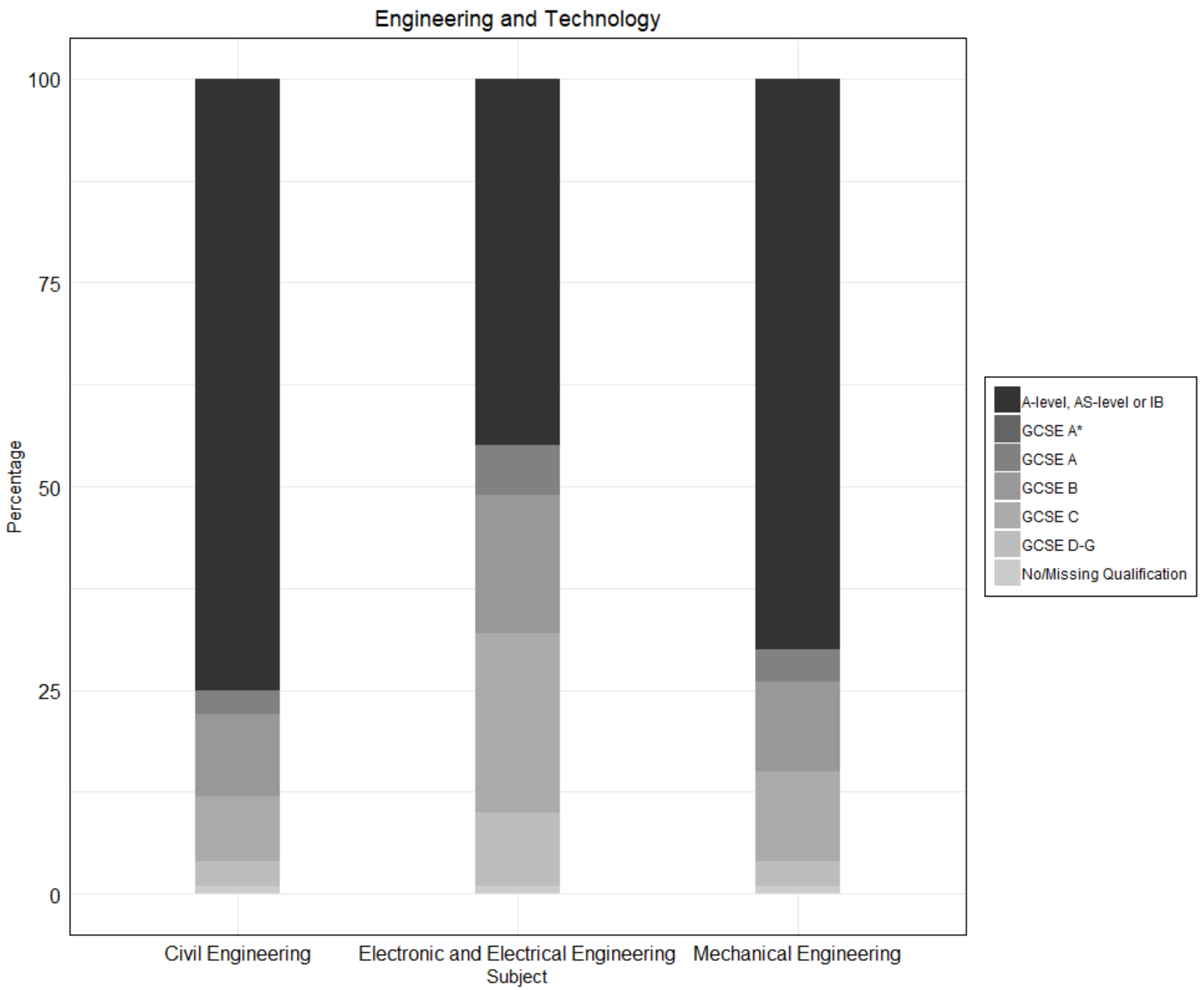

Figure 1: The distribution of the GCSE Mathematics grade for students without any level 3 Mathematics qualification in Civil, Electronic and Electrical, and Mechanical Engineering.

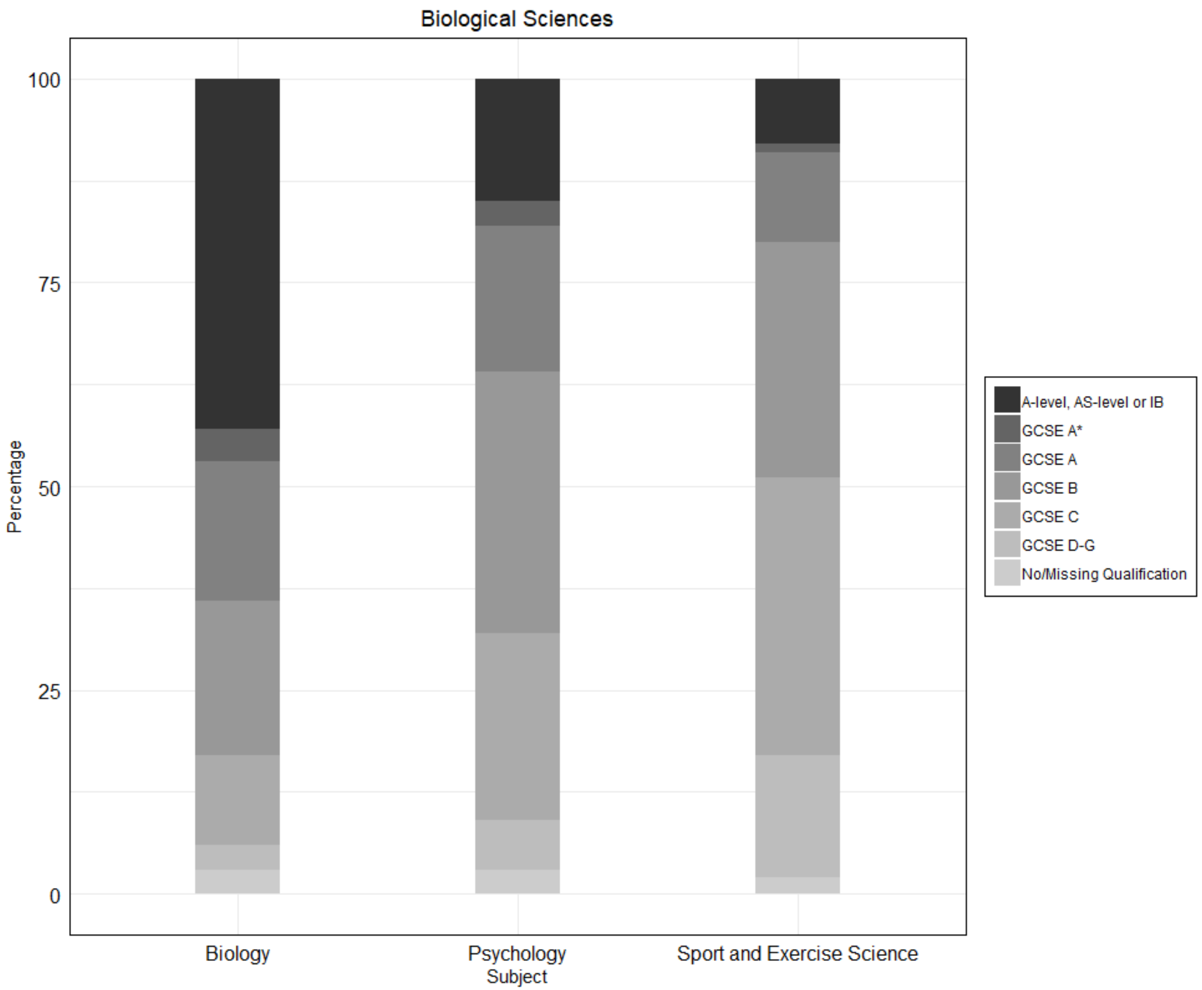

Figure 2: The distribution of the GCSE Mathematics grade for students without any level 3 mathematics qualification in Biology, Psychology and Sport and Exercise Science.

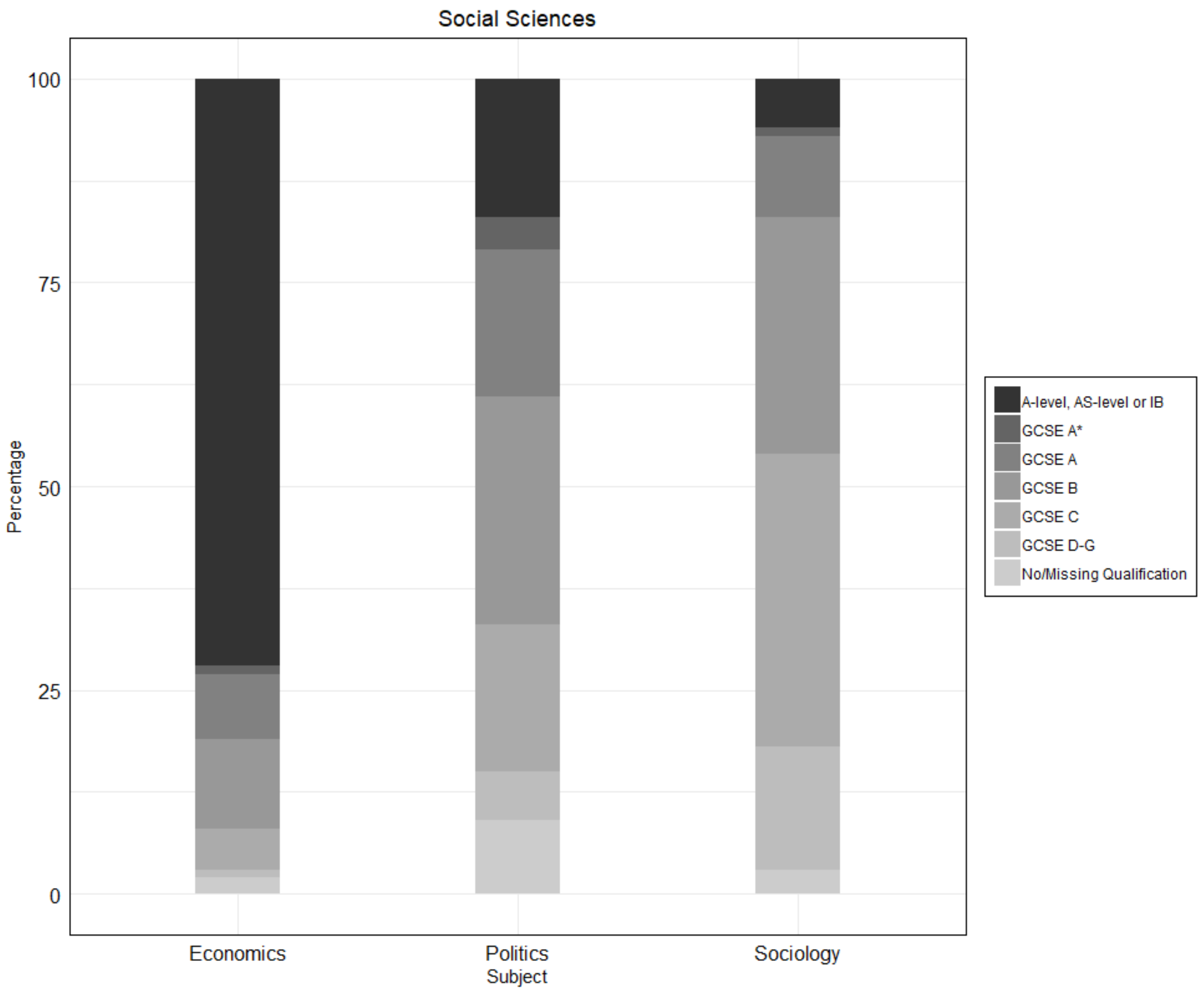

Figure 3: The distribution of the GCSE Mathematics grade for students without any level 3 mathematics qualification in Economics, Politics, and Sociology.

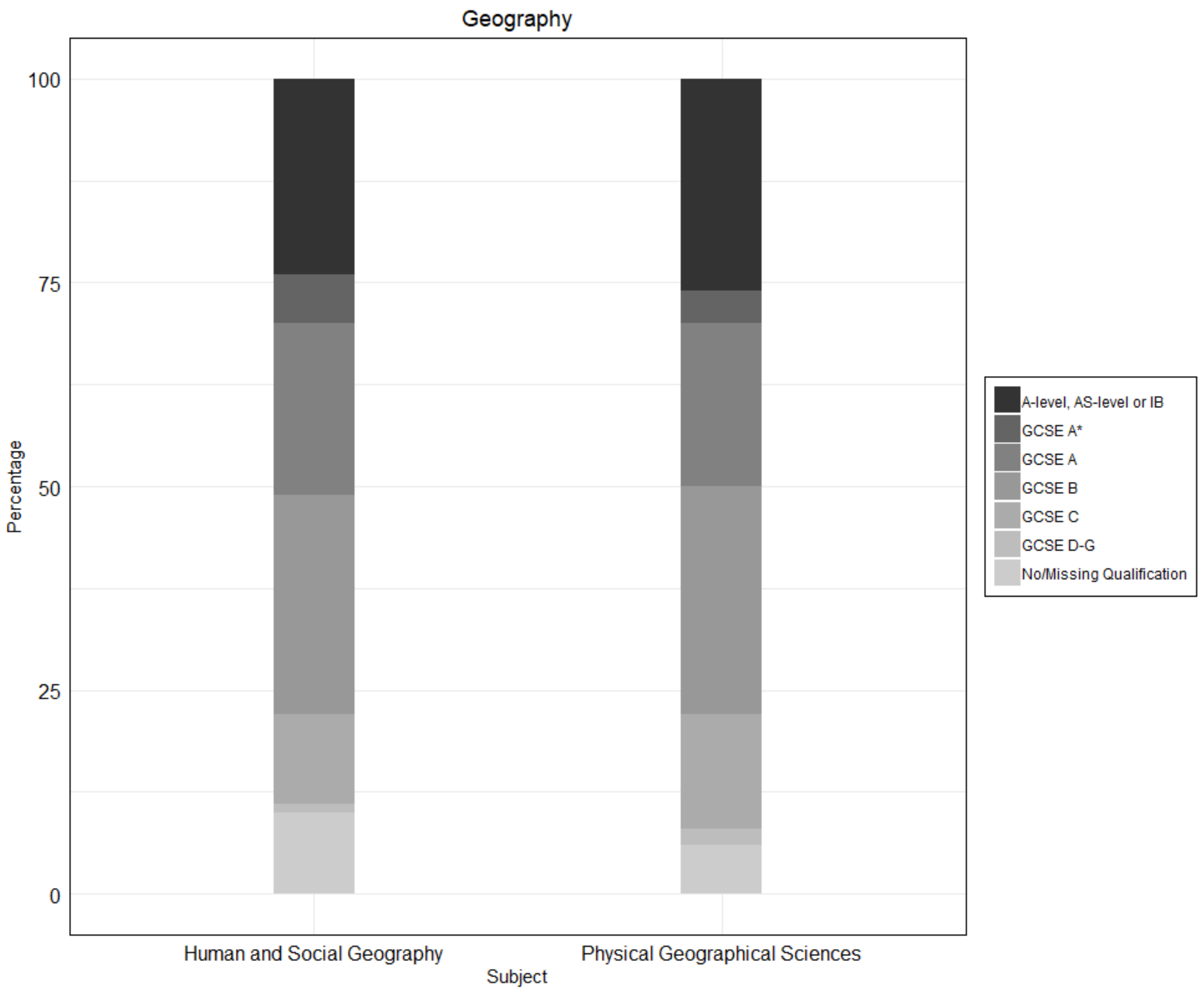

Figure 4: The distribution of the GCSE Mathematics grade for students without any level 3 mathematics qualification in Physical and Human and Social Geography

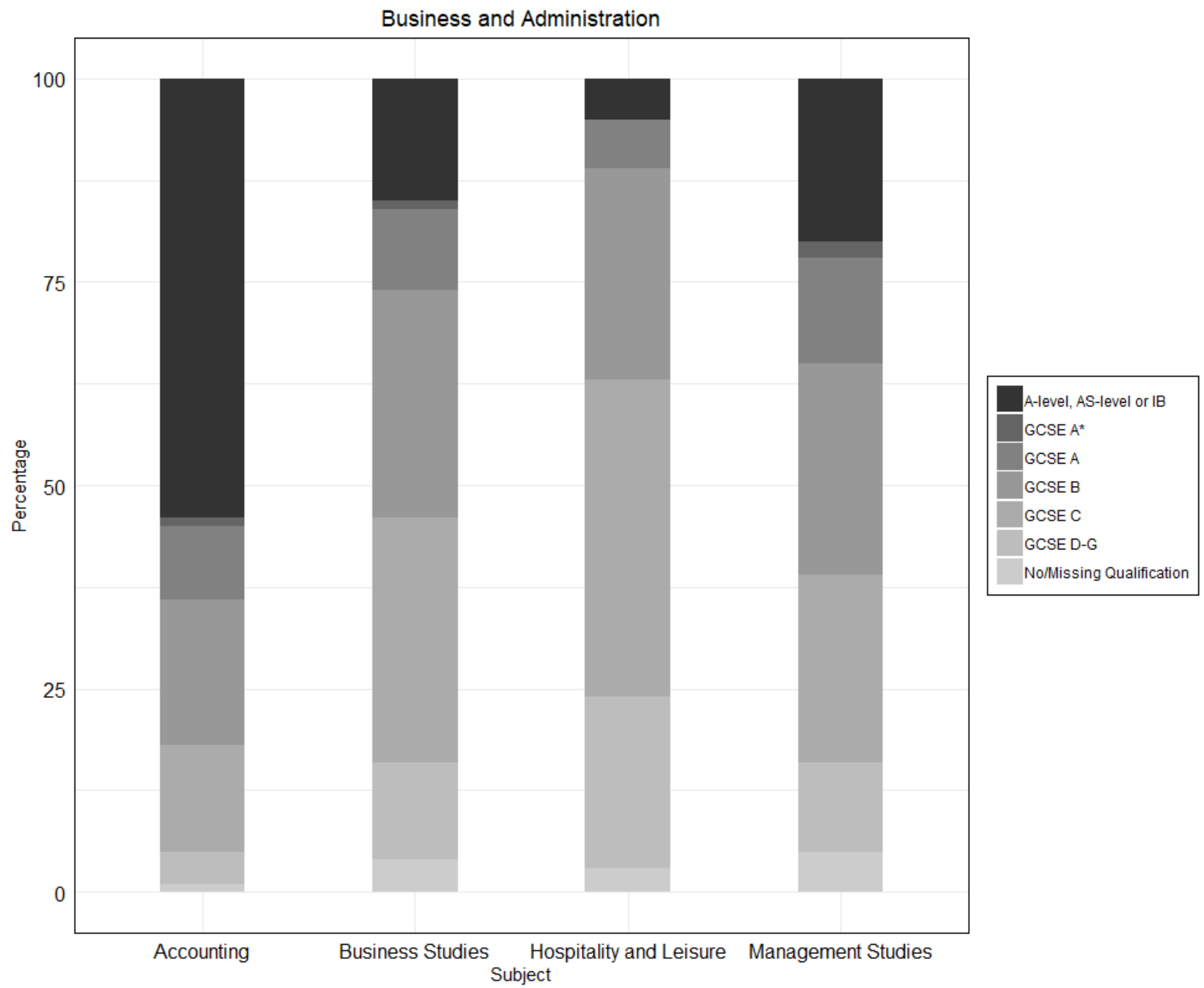

Figure 5: The distribution of the GCSE Mathematics grade for students without any level 3 mathematics qualification in Accounting, Business Studies, Hospitality, leisure, sport, tourism and transport, and Management Studies.

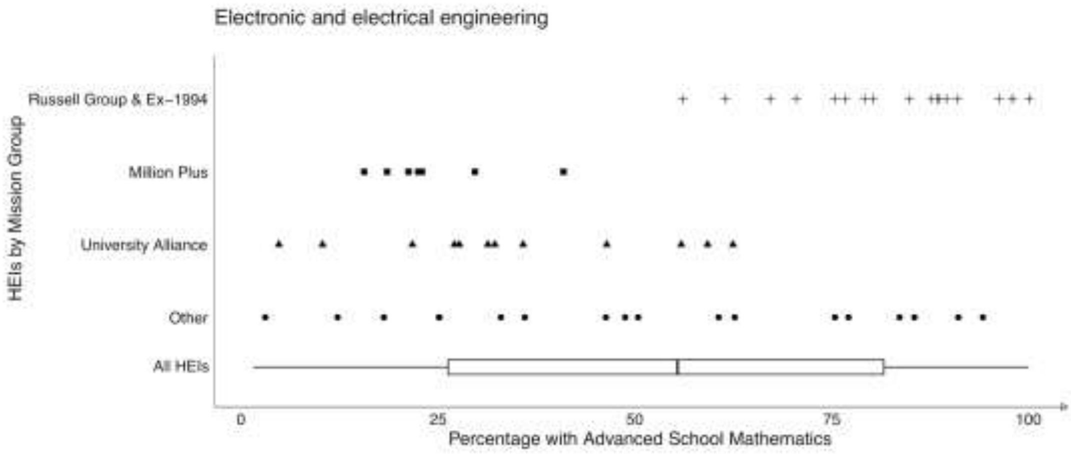

Figure 6: The distribution of students with an advanced school mathematics qualification for university mission groups in Electronic and Electrical Engineering. Note: due to the small number of ex-1994 institutions, the Russell and ex-1994 Groups were collapsed into one category in accordance with the requirements of our data disclosure agreement.

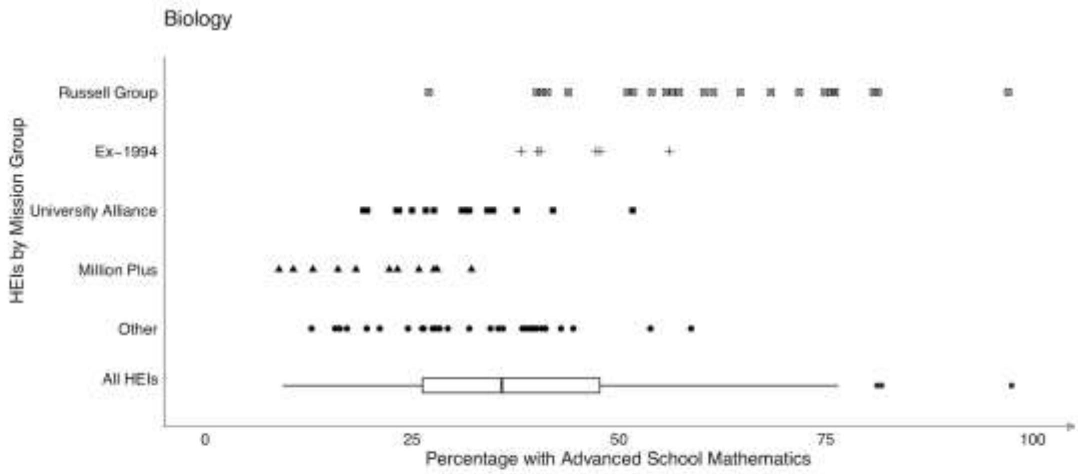

Figure 7: The distribution of students with an advanced school mathematics qualification for different university mission groups in Biology.

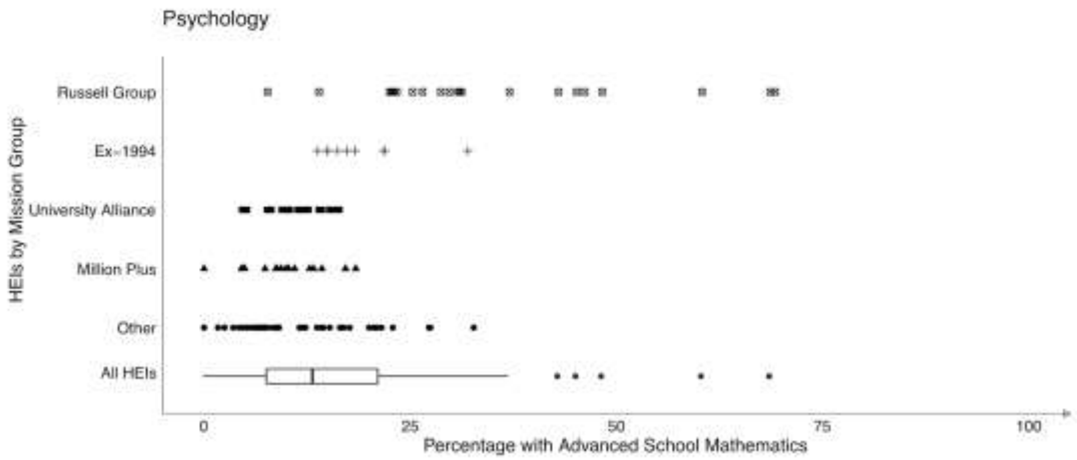

Figure 8: The distribution of students with an advanced school mathematics qualification for different mission groups in Psychology.

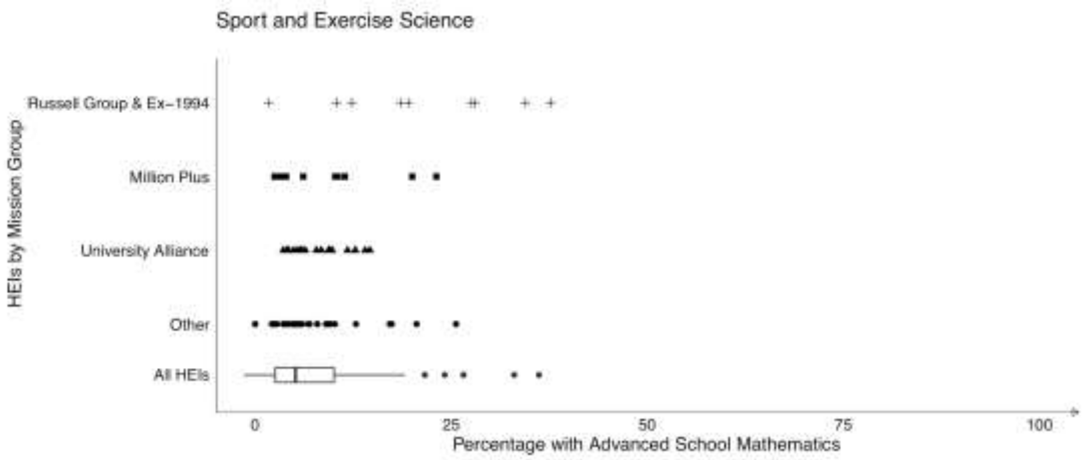

Figure 9: The distribution of students with an advanced school mathematics qualification for different mission groups in Sport and Exercise Science. Note: due to the small number of ex-1994 institutions, the Russell and ex-1994 Groups were collapsed into one category in accordance with the requirements of our data disclosure agreement.

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