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The Mathematics needs of prospective Architecture undergraduates

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Background to the study

The General Certificate of Education (GCE) Advanced level (A level) qualifications in Mathematics and Further Mathematics are being reformed for first teaching in England in 2017. All A levels are moving from a modular to a linear system, requiring students to take their examinations at the end of a two-year course, rather than throughout as is currently the case. Furthermore, the Office of Qualifications and Examinations Regulation (Ofqual), the regulator of qualifications in England, and the Department for Education (DfE) have introduced 100 per cent prescribed content for A level Mathematics, and 50 per cent prescribed content for A level Further Mathematics. Although this will help reduce the variability in students' mathematical backgrounds when entering university, the Applied Mathematics content (Statistics, Mechanics or Decision Mathematics) that students are able to study will inevitably be reduced.

These two qualifications prepare students for undergraduate study in a wide range of subjects, including Science and Social Science in addition to tertiary Mathematics. Consequently, the reforms will have implications for a large number of prospective students' readiness for undergraduate study. This article reports on current undergraduate architects' perceptions of the existing A levels as preparation for undergraduate Architecture, including the Applied Mathematics content they perceived to be most useful. Architecture was a chosen subject of focus as it is a field of study which requires some mathematical understanding, yet there is no existing research on Architecture undergraduates' mathematical abilities in the United Kingdom (UK) context.

Undergraduate Architecture

Undergraduate Architecture degrees are traditionally the first step in the process of becoming a professional architect. Some undergraduate courses form part of the formal training process as they are accredited by the Architects Registration Board (ARB), which ensures that they comply with particular skills requirements. Although not all undergraduate courses entitled 'Architecture' are officially accredited, there is nonetheless a direct link between the skills required in the Architecture profession and the content of Architecture degrees.

No university in the UK currently requires a post-compulsory Mathematics qualification for admission to study Architecture. The Universities of Bath and Cambridge both recommend A level Mathematics, whilst other universities set a minimum entry requirement of a grade C or above at GCSE[1].

Nonetheless, a relatively high proportion of students entering Architecture, Building and Planning[2] courses have taken at least A level Mathematics. In 2010, 42.8% of first year students in these disciplines had studied Mathematics at A level, and 3.9% had studied Further Mathematics (Vidal Rodeiro & Sutch, 2013). Consequently, whilst mathematical entry requirements may be limited, the high percentage of Architecture students with a post-compulsory Mathematics qualification suggests that students may perceive further study in Mathematics to be either relevant or helpful to their undergraduate aspirations.

Many universities require prospective Architecture students to have an Art qualification or to present a portfolio with their application. Perhaps reflecting this, the most popular A level subject amongst new Architecture, Building and Planning undergraduates was Art and Design (45.8%), followed by Mathematics and Physics (20.8%) (Vidal Rodeiro & Sutch, 2013).

Mathematics in Architecture

The disciplines of Architecture and Mathematics are considered to have a close relationship, predominantly because of the importance of geometry in architectural design. Traditionally there has been a focus on Euclidean geometry, although the rise of modernism in Architecture has led to a recent interest in newer topics such as fractal and topological geometry (Cikis, 2010; Megahed, 2013; Salingaros, 1999).

The Mathematics content in university Architecture courses can be broadly classified into three areas:

1. General Mathematics, based on calculus and algebra;
2. Applied Mathematics, predominantly related to building construction; and
3. Design-orientated Mathematics, including areas such as geometry and proportion.

The emphasis on Applied Mathematics, in particular the Mathematics needed in Building Design and Construction, is reflected in the incorporation of Architecture courses into Engineering faculties in countries such as Egypt. Cikis (2010) reviewed the mathematical content of Architecture courses in the United States of America (USA) and Europe and found that the most frequently occurring topics were calculus, descriptive geometry, geometry and analytical geometry, Applied Mathematics, and trigonometry (in decreasing order of frequency).

1. Correct at December 2015.
2. Architecture is grouped with Building and Planning by the Universities and Colleges Admissions Service (UCAS) when they supply applications data.

Additionally, the growing use of computer-aided design software (CAD) in architectural design has led some authors to argue that Architecture students should be aware of the mathematical principles behind the software they are using. In particular, an understanding of algorithms as well as parametric and linear modelling would be potentially useful skills for undergraduates (Cikis, 2010; Freiberger, 2007; Megahed, 2013).

There is, however, some indication that undergraduate architects may not necessarily be able to apply the mathematical content of their degrees directly to architectural design. Verner and Maor (2003) tested Architecture students in Israel and found that, whilst the students appreciated the relevance of Mathematics to design, they performed badly on a test which was designed to assess core mathematical concepts related to Architecture. Consequently, they designed a new Mathematics programme that focused on a problem-solving approach, which directly applied the mathematical concepts they were learning to architectural problems. Students who took this course performed better when re-tested than a control group who had not been taught the problem-solving approach. The importance and relative use of problem-solving in relating Mathematics to Architecture has been reiterated elsewhere, with Javier and Cepeda (2005) implementing a similar programme in an Architecture courses in Mexico. They found that students were more likely to engage with the Mathematics content of their courses when it was directly applied to architectural design.

Furthermore, Cikis (2010) raises a concern that, despite the historical relationship between Mathematics and Architecture, there is a disconnect between the Mathematics that students are required to study as an undergraduate and the Mathematics the undergraduates will eventually use in their professional careers. He argues:

> *The knowledge of Mathematics required by an ordinary architect to carry out his/her profession is at quite a simple level and, unless a very special situation arises, an architect can carry out all sorts of professional duties without resorting to any higher mathematical knowledge.* (p.106)

This is corroborated by the benchmark statement for Architecture (Quality Assurance Agency for Higher Education, 2010) and the ARB criteria for graduate architects, which make no reference to mathematical skills, apart from references to strategies for building construction and the ability to "critically examine the financial factors in varying building types, construction systems, and specification choices" (ARB, 2010, p.6).

The lack of an overt presence of Mathematics in professional Architecture may mean that potential students do not recognise the importance of Mathematics to either their undergraduate studies or their future career. However, there has not, as yet, been any research conducted assessing the mathematical preparedness of undergraduates for Architecture courses in the UK.

Content and structure of A level Mathematics and Further Mathematics

This article reports on findings from a large-scale project investigating current undergraduates' perceptions of existing A levels in Mathematics and Further Mathematics. This research was conducted in response to the forthcoming changes to these A levels from 2017 (DfE, 2013). As discussed previously, these reforms will entail significant changes to both the content and structure of these qualifications. This research thus investigated undergraduates' perspectives of the current A levels in order to inform development of the new specifications, as well as to consider the implications of the reforms for universities and prospective students. The current structures of A level Mathematics and Further Mathematics will now be discussed in more depth.

AS and A level Mathematics

At present, A level Mathematics comprises four compulsory Core Pure Mathematics units of equal weighting, with two Applied Mathematics units. These units may be chosen from one of three different strands:

1. Mechanics;
2. Statistics; and
3. Decision Mathematics.

Within each of these strands there are between two and five sequential units, depending on the strand and awarding body. The more advanced Applied Mathematics units (e.g., Mechanics 3 and above) can only be studied in AS or A level Further Mathematics.

Students are able to take either two units from the same strand (e.g., Mechanics 1 and Mechanics 2) or one from two different strands (e.g., Statistics 1 and Decision Mathematics 1). Hence, there are six[3] possible routes through A level Mathematics.

At AS level, students must take two compulsory Core Pure Mathematics units and one applied unit (Mechanics 1, Statistics 1 or Decision Mathematics 1).

It is not necessarily the case that students will be able to take the units that they want to. Restrictions on resources and timetabling within schools and colleges may mean that students are given a restricted choice, if at all.

AS and A level Further Mathematics

A level Further Mathematics comprises two compulsory Further Pure Mathematics units, plus four optional units. At AS level, students must take Further Pure Mathematics 1 and two optional units.

The optional units can be selected from any of the three standard strands offered within A level Mathematics[4] (Mechanics, Statistics and Decision Mathematics) or from an additional two Further Pure Mathematics units. There are therefore a large number of different routes through Further Mathematics.

Method and analysis

All universities which offer Architecture degrees were sent emails, using the contact details on departmental websites, requesting participation. Departments were asked to pass on the details of an online questionnaire aimed at students who fulfilled two criteria, namely:

- They must have been in their second year of study or above, in order that they could reflect on their experiences so far;
- They must have taken at least AS level Mathematics since 2006, when the qualification underwent its most recent restructuring.

Those who took International A levels were not permitted to take part.

3. These are: (1) M1 + M2; (2) S1 + S2; (3) D1 + D2; (4) M1 + S1; (5) M1 + D1; (6) S1 + D1.
4. Students are not allowed to take units as part of AS or A level Further Mathematics that they have already taken as part of AS or A level Mathematics.

The questionnaire surveyed students regarding:

- their **mathematical background** (e.g., highest Mathematics qualification, grades achieved, awarding body of Mathematics and/or Further Mathematics qualifications, units studied as part of AS or A level Mathematics and/or Further Mathematics);
- their **current studies** (e.g., university, degree type and title, year of study);
- their **perception of the A level(s)** as preparation for the mathematical component of their degree, both overall and by optional units;
- the **factors which motivated them to take Further Mathematics** (if applicable); and
- their **experience of Further Mathematics** (if applicable).

The questionnaire comprised a mixture of multiple choice questions, closed questions and open-ended questions. It was developed by the authors and an A level Mathematics expert, before being piloted by three recent graduates of mathematically-demanding degrees. Small changes were made in response to the piloting. The questionnaire was made available in an online format, and was open for responses between September and December 2014.

Analysis of quantitative data was conducted using SPSS (a software package used for statistical analysis), and qualitative responses to open-ended questions regarding the qualification(s) as preparation for undergraduate Architecture were coded using MAXQDA (a software package for qualitative and mixed methods data analysis). Thematic analysis was used in order to analyse and later describe participants' views of the qualification(s) and any suggestions they had for how they could have better suited their needs.

Data

Data were collected between October and December 2014, during the first term of the academic year.

Sample

After incomplete and inappropriate responses were removed as part of the data cleaning process, 37 students studying undergraduate degrees in Architecture had completed the questionnaire.

- **University:** Participants came from 7 different universities, all of which were ranked in the top 75 per cent of the 51 Architecture departments listed in the *Complete University Guide* (2015). All participants were studying for courses accredited by the ARB.
- **Year:** Half of the participants were in their second year of study, and the remainder in their third year.
- **Degree programme:** All students were studying for single honours degrees entitled 'Architecture'. Three were studying for (four-year) undergraduate Master's degrees, with the rest for (three-year) Bachelor's degrees.

A level results

All participants had studied more post-compulsory Mathematics than is required by any UK university for admission to Architecture. Most had studied a full A level in Mathematics, with over one-third (15 students) having also studied either AS or A level Further Mathematics (see Table 1).

Table 1: Participants' highest Mathematics qualification

Qualification	*No. participants*	*%*
AS level Mathematics	1	2.7
A level Mathematics	21	56.8
AS level Further Mathematics	6	16.2
A level Further Mathematics	9	24.3
Total	**37**	**100.0**

The majority of participants (58.3%) who took A level Mathematics achieved an A*. The rest achieved a grade A (19.4%), a grade C (16.7%) or a grade E (5.6%). In 2011, only 13.3% of Architecture undergraduates who had studied A level Mathematics achieved an A* (Vidal Rodeiro, 2012). The sample here is therefore skewed to the higher end of achievement compared to both all A level Mathematics candidates and undergraduate Architecture students.

All of the 15 participants who had taken at least AS level Further Mathematics achieved at least a grade A. This is obviously higher than the national figures, wherein 56.3% achieved a grade A or A* above in A level Further Mathematics (Joint Council for Qualifications [JCQ], 2015), further indicating that the students in the sample were particularly high-achieving students at A level.

A level units

Similar proportions of participants studied Mechanics to those who studied Statistics units as part of their Mathematics qualifications (see Figure 1). It was rare for participants to have taken more than two applied units in the same strand, although this is skewed by the fact that the majority of participants had not studied Further Mathematics. Decision Mathematics was the least commonly-taken optional applied unit amongst the participants.

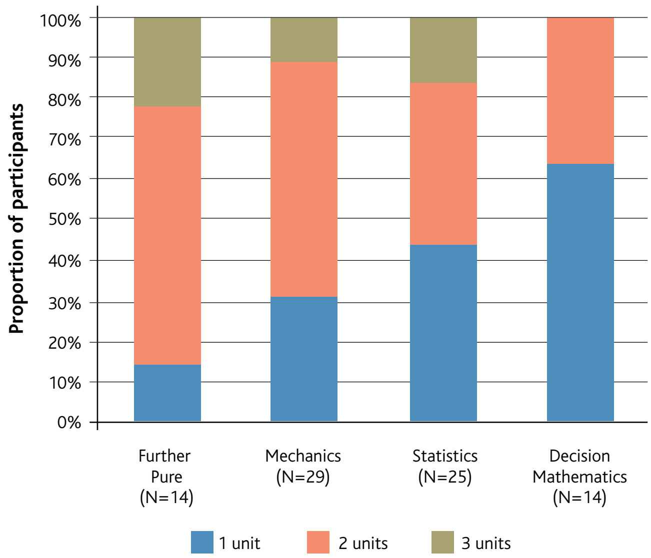

Figure 1: Number of optional units studied by Architecture students

It should be noted that the number of participants who studied Further Pure Mathematics units is low compared to the other strands because these units are only available as part of AS or A level Further Mathematics.

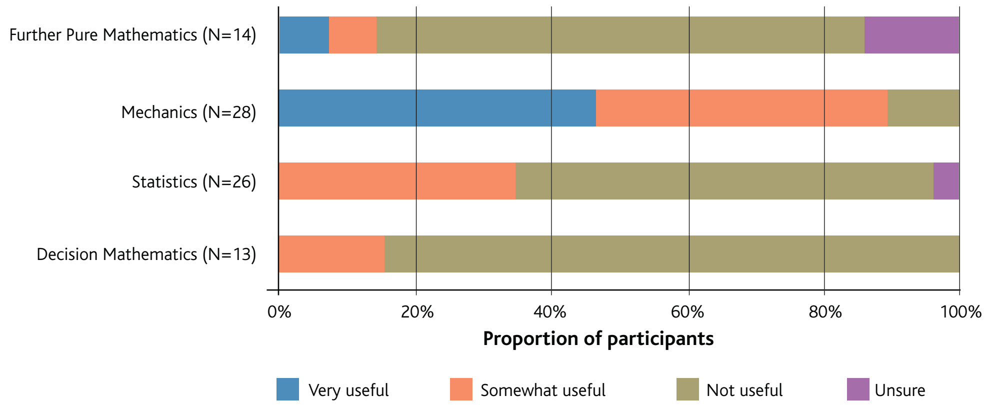

Figure 2: Architecture students' views of the utility of optional units

Experiences of non-compulsory A level units

The applied strand which participants considered to be the most useful preparation for Architecture degrees were Mechanics (see Figure 2). Nearly half (46.4%) of the participants described Mechanics as 'very useful', and only three participants declared it 'not useful'. No participants who had taken Decision Mathematics found it to be useful preparation for their degree, and Statistics was described as 'somewhat useful' (34.6% of participants) at best. For those students who had taken AS or A level Further Mathematics, Further Pure units were also less well-received, with only two participants describing it as either 'very' or 'somewhat useful'.

A level as preparation for the mathematical component of Architecture

A level Mathematics was described as good preparation for Architecture degrees by 75.7% of participants, and only one participant reported that it was bad preparation (see Figure 3). However, students were less positive about Further Mathematics. Of those who had studied Further Mathematics, less than half reported that it was good preparation for their degree.

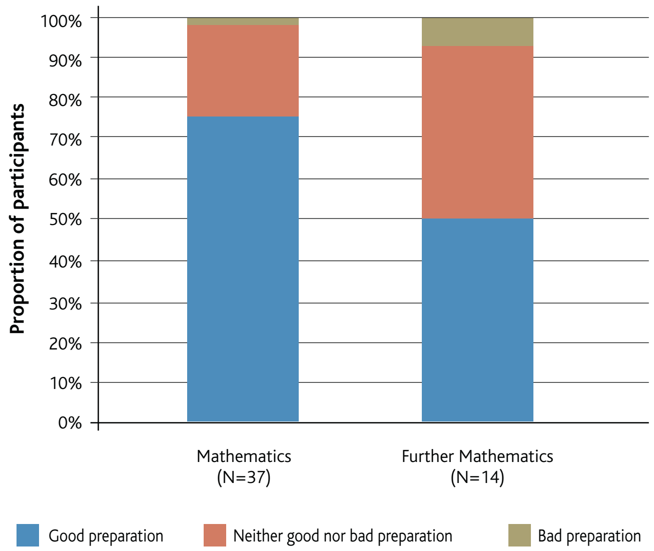

Figure 3: The A levels as preparation for undergraduate Architecture

This suggests that, though few students regarded Further Mathematics as bad preparation, Further Mathematics was perceived by the participants who took it to have had less additional benefit to A level Mathematics compared to studying other subjects. However, the low number of responses to this question, should be taken into account (*N*=14).

Improvements to A level Mathematics and Further Mathematics

Participants were also asked two open response questions:

1. Were there any topics that they would have found useful to have been included in A level Mathematics and Further Mathematics?
2. Could any improvements be made to these A levels in order to better prepare students for the mathematical components of Architecture degrees?

There were sixteen responses to the first question. The majority of students reported that there were no additional topics that would have been useful. They stated that A level study had prepared them well, particularly the Mechanics units. Indeed, a minority of participants indicated that they had not encountered any Mathematics in their degree which was more difficult than at A level. Suggestions for additional topics focused on increasing the proportion of Mechanics and structural Mathematics available to students and making this area compulsory. Nevertheless, two participants acknowledged that they had been unable to study Mechanics units because of restrictions at their school.

Twenty-four students commented on whether the A levels in Mathematics and Further Mathematics could provide better preparation for their undergraduate courses. The responses were very similar to those to the previous questions. Three students reported that their degree actually required very little Mathematics knowledge, and therefore A level Mathematics was sufficient preparation. Additionally, one participant who had studied A level Further Mathematics reported that it was enjoyable but largely irrelevant to their course.

Many reported that they would have preferred more Mechanics content at A level, as most students considered this strand to be the most relevant content for undergraduate Architecture and therefore the most useful preparation. The majority of students who offered suggestions for improvements stated that more practical applications and problem-solving at A level would be useful, as well as the use of real-world examples.

Discussion and conclusion

The data collected indicate that Mechanics units were considered by Architecture undergraduates to be the most useful optional units as preparation for the mathematical content of their university studies. The apparent utility of Mechanics correlates with the literature, due to the need for Architecture undergraduates to consider the Mathematics involved in Building Construction. This type of Mathematics requires an awareness of forces and kinematics, as well as the mathematical modelling of real-life problems which has its foundations in Mechanics.

Conversely, participants were considerably more negative about the utility of Decision Mathematics and Statistics units. No student reported that they found either unit to be good preparation for their degree. The negative perception of the Statistics units may be unsurprising given that Statistics is not considered to have an essential role in architectural Mathematics. However, an awareness of probability and Statistics may be useful when considering factors such as construction programmes and building costs (Megahed, 2013).

Students' negative perceptions of Decision Mathematics are especially relevant when considering the types of Mathematics that Architecture students will encounter during their degrees. The use of CAD software is becoming more widespread in undergraduate Architecture courses, and it may therefore be useful for Architecture students to understand the Mathematics behind this. Consequently, algorithmic thinking and linear programming have thus been identified as potentially useful mathematical skills for undergraduate architects (Freiberger, 2007; Megahed, 2013). Both of these areas currently are taught in the Decision Mathematics strand at A level. However, the perceived negative utility of Decision Mathematics by Architecture students may indicate that Architecture students struggle to see the relevance of these topics and apply these skills during their undergraduate studies. Additionally, Architecture students were least likely to take a Decision Mathematics unit than either Mechanics or Statistics, meaning that their exposure to these areas of Mathematics may be low. The extent to which A level reform will mitigate these concerns is currently unclear. There will be no Decision Mathematics in A level Mathematics, as a result of the recommendation of the A Level Content and Advisory Board (ALCAB) that these units should be removed from the reformed A levels. This recommendation was made based on universities' perceptions of existing Decision Mathematics units as irrelevant to undergraduate mathematical study and as 'soft' options (ALCAB, 2014, p.8). Nevertheless, the awarding bodies may opt to include some Decision Mathematics content in Further Mathematics. This means that in future, it will be very unlikely that potential architects will have any experience with areas such as linear programming before beginning university study.

Additionally, the data indicate that, whilst A level Mathematics is a useful subject for undergraduate Architects to have studied, there appears to be more limited use in having studied Further Mathematics. Fewer than half of participants who had studied either AS or A level Further Mathematics agreed that it had been good preparation for the mathematical content of their degree. The perceived lack of utility in Further Pure units may also be surprising, considering that Cikis (2010) found that the majority of the Mathematics components in Architecture courses in the USA and Europe focused on calculus. Calculus, principally more complex differentiation and integration, forms a significant part of Further Mathematics qualifications. It may therefore be expected that taking Further Mathematics would be useful preparation for prospective architects. However, geometry is also a key mathematical concept in Architecture courses and there is very little geometry in Further Mathematics. Therefore, it is likely that a large proportion of the content in Further Mathematics is irrelevant to the mathematical content in undergraduate Architecture. The subject criteria for the reformed A levels in both subjects indicate that this is unlikely to change in the future, as there is no geometry in the prescribed content for the reformed A level Further Mathematics (DfE, 2014).

Consequently, it is essential that prospective architects are given appropriate guidance about the post-compulsory Mathematics qualifications they should take. Whilst very few universities currently stipulate Mathematics A level as an entry requirement for Architecture, the data collected in this research indicate that it would be a useful qualification for students considering a degree in Architecture to have. Unfortunately, there is little literature regarding how and when students usually decide which subject to study at university in relation to when they choose their A level subjects. The decision could have been made prior to A level choices, and thus students may make an appropriate decision to study A level Mathematics and/or Further Mathematics. However, if students choose to study Architecture once they have already begun studying their A levels, then they may not be able to choose an appropriate post-compulsory Mathematics qualification. For the most part, students do not change their minds regarding what subject they wish to study at university after age 16 (Sutch, Zanini & Benton, 2015). Therefore, it is important that students are given appropriate advice regarding the most appropriate A levels to take as preparation for certain degree courses when making their subject decisions. It is not necessarily the case that the only useful A levels are those subjects that are explicitly required by university entry requirements. The introduction of the new Core Mathematics qualifications also warrants mention here, as this may be a useful qualification for prospective Architecture students who wish to continue studying Mathematics in Further Education but do not wish to study the A level.

For those students who do choose to study A level Mathematics or Further Mathematics, guidance on what optional units would be helpful mathematical preparation is very important. Prospective Architecture undergraduates would benefit from studying Mechanics content. Whilst Mechanics units are currently optional, the reformed A level Mathematics will have prescribed Mechanics content, meaning that all future Architecture students taking this A level will study Mechanics prior to beginning their university studies. Additionally, there currently appears to be limited use in taking Further Mathematics in its current form as preparation for the mathematical content in undergraduate Architecture. However, after the reforms, it will only be possible for A level students to specialise in Mechanics by taking Further Mathematics. Hence, admissions tutors, students and teachers should be made aware that Further Mathematics may serve a stronger purpose as preparation for the mathematical component of Architecture in the future.

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Assessing the equivalencies of the UCAS tariff for different qualifications

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Introduction

In the United Kingdom (UK) the Universities and College Admissions Service (UCAS) provides the application process for most universities. The UCAS tariff points system is used by universities to help them select students for their courses. Each grade in eligible qualifications is allocated a points score, which can then be summed in order to provide an overall points score for each student. The allocation of points is such that, in theory, students with the same overall points score gained from different qualifications can be considered to be of equivalent ability or potential. The purpose of this article is to test whether this assumption works in practice, by calculating empirical equivalencies of the UCAS tariff for different qualifications.

In the past, UCAS has undertaken studies to try and determine what the tariff points scores should be for different grades achieved in any new qualifications to be considered under the tariff (e.g., UCAS, 2003; 2006). These included comparability studies carried out by an 'expert group', which compared the new qualification with a similar, benchmark qualification and provided recommendations for the number of tariff points allocated to each grade on the qualification. For example, the BTEC Nationals were first included in the tariff tables in 2003 following a comparability study with AQA's Advanced Certificates of Vocational Education (UCAS, 2003).

In these UCAS reports it is noted that a future review of the tariff points allocated to the qualification might be necessary once more evidence becomes available and once Higher Education (HE) admissions tutors have more experience in using the qualification to admit students. However, it is not clear how often this actually happens for individual qualifications. One study that did attempt to address this issue was undertaken by Green and Vignoles (2012). They used the future performance of students at university to make an empirical comparison between the tariff points allocated to A levels and the International Baccalaureate (IB) qualification. The present article seeks to update and extend their work by using more recent data and by also including BTEC qualifications in the comparisons.

One way of investigating the equivalence of tariff points for different qualifications is to compare the outcomes in terms of degree classification for students with the same UCAS tariff obtained from different qualifications. For example, Figure 1 shows the percentages of students achieving a First-class degree or at least an Upper Second-class degree, by their UCAS tariff score (tariff scores where fewer than 30 students achieved that score were excluded). Different lines are presented for students taking different qualifications (General Certificate of Education [GCE] Advanced levels [A levels] only, BTECs only, IB only or mixed).

This would seem to suggest that the current tariffs over-value BTECs and the IB compared with A levels, as the percentage of students achieving a First or at least an Upper Second is higher for A level students at any given UCAS tariff (except for IB students at the very top). However, this analysis does not take into account other factors that might have an influence on the probability of a good degree for a given UCAS tariff. These include the school and university attended and the degree subject, as well as student background characteristics such as gender and socio-economic background.

Data

The data for this research came from a linked dataset requested from the Department for Education. This request consisted of data from the National Pupil Database (NPD) and from the Higher Education Statistics Agency (HESA) student records' database, linked by a common student identifier. The data included information on:

- Degree studied by each student:
  - Institution identifier (anonymous)
  - Subject of study – subjects were classified into one of twenty different subject groups
  - Degree classification – First, Upper Second, Lower Second, Third (or below).