Post-16 Mathematics Qualifications As Preparation For Quantitative Study In Higher Education

by

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Impact of COVID-19

This project started in October 2018 and was originally intended to be conducted as a pilot study that would be followed in the subsequent year by a larger main study. However, shortly after finishing the collection of data for the first (intended pilot) study in February 2020, we were impacted by the Government's national and the University's additional COVID-19 regulations which were put in place to control the spread of infection. This, in turn, restricted the way in which we could collect data and meant that we had to postpone the planned main study due to the necessary and significant changes that we would have to make to the study methodology.

After a period of intermission, we redesigned the study methodology so that it could be reliably conducted in an online environment without the supervision of research assistants. Unfortunately, however, our method of advertising the study relied heavily on email communication which resulted in an under-recruitment of the target number of participants to what was stated in our pre-registration. As such, we decided that it was necessary to conduct a further study which also recruited participants from other university institutions. This meant that we needed to request approval from the University to extend the project by an additional year to include a hybrid study of participants in a lab-based environment and participants who completed the study online.

We did, however, use the COVID-19 pandemic as an opportunity to collect data about students' perceived impact of the pandemic on their education when starting at university and it has resulted in a total of four studies across three separate years.

Abstract

This research aims to provide evidence of the quantitative performance of students when starting at university in relation to their previous mathematics education experience. The UK has a low uptake of mathematics after it ceases to become compulsory at the age of 16 which has led to a widespread shortage of mathematics-based skills in Higher Education when compared to other countries. This is problematic for students starting at university since we estimate that approximately over half of university departments will teach some quantitative elements, yet it is thought that up to 80% of students will not have studied a mathematics-based subject for at least two years (A. Smith, 2017). These factors, in combination with recent major reforms to the UK education system and the introduction of more accessible post-16 mathematics qualifications, make this an opportune time to gather evidence at a Higher Education level in the wake of these major changes to the UK education landscape. This research consists of four studies: (1) a lab-based survey that took place prior to the COVID-19 pandemic and investigated predictors of quantitative performance; (2) an online-based survey that took place during the COVID-19 pandemic and focused on quantitative performance in relation to confidence and mathematics anxiety as well as the perceived effects of the pandemic on participants' education; a hybrid of (3) a lab-based and (4) an online-based survey which took place after the COVID-19 pandemic and was conducted at multiple institutions. The four studies each consisted of a pre-test which offered to provide an insight into a participant's quantitative performance when starting at university and a post-test which collected evidence again after one term of university study. The findings showed that studying mathematics between the ages of 16-18 was beneficial for university study with individuals who had studied a post-16 mathematics qualification exhibiting better quantitative performance, lower levels of mathematics anxiety and higher levels of confidence than individuals who had not. We also found evidence that certain personality traits were beneficial for mathematics performance. We believe that the findings of this research provides the foundation for universities to consider the messaging given to students regarding post-16 mathematics qualifications, and it is hoped that more positive support from Higher Education institutions will lead to a higher uptake of mathematics studied between the ages of 16-18.

Publications and Conferences

Throughout my PhD, I have collaborated on a range of research in the field of Mathematics Education at the University of Essex. I have presented research findings at conferences, in articles and in peer-reviewed publications. At the time of submission I am intending to publish the work in this thesis as part of two papers, the first of which is already in draft and will be uploaded to a preprint server.

Manuscripts in Preparation

Partner, A., Lausen, A., Vernitski, A., Saker, C., & Lausen, B. (2025). *The benefits of post-16 mathematics qualifications for first-year undergraduate students*. Manuscript in preparation based on the research presented in Chapter 4 of this thesis.

Partner, A., Lausen, A., Vernitski, A., Saker, C., & Lausen, B. (2025). *Analysing post-16 mathematics qualifications as predictors for success in Higher Education: A two-wave study coinciding with the educational impact of COVID-19*. Manuscript in preparation based on the research presented in Chapters 5 and 6 of this thesis.

Conference Presentations

Partner, A., Lausen, B., Lee, S., Nordmark, H., Sahli, M., & Saker, C. (2019, August 26-29). *Data Science Education, Skills and Industry in Europe* [conference presentation]. International Federation of Classification Societies (IFCS), Thessaloniki, Greece.

Partner, A., Lausen, A., Vernitski, A., Saker, C., & Lausen, B. (2022, July 19-23). *Predictors of Quantitative Skills in Degree Schemes at University* [conference presentation]. International Federation of Classification Societies (IFCS), Porto, Portugal.

The Conversation Articles

Partner, A., & Vernitski, A. (2021, July 12). Studying maths post-GCSEs aids brain development - should it be compulsory? *The Conversation*.

Partner, A., & Vernitski, A. (2023, January 5). Rishi Sunak is right about a lack of maths skills in England: here's how plans to extend teaching could work. *The Conversation*.

Peer-Reviewed Publications

Partner, A., & Vernitski, A. (2023). Maths lecturers in denial about their own maths practice? A case of teaching matrix operations to undergraduate students. *MSOR Connections*, 21(3). https://doi.org/10.21100/msor.v21i3

Bailey, J., Claridge, J., & Partner, A. (2024). Investigating students' perception of the importance of calculus: a cross-discipline comparison to inform module development. *MSOR Connections*, 22(1). https://doi.org/10.21100/msor.v22i1

Declaration of Originality

The work in this thesis is based on research that has been conducted at the School of Mathematics, Statistics and Actuarial Science, University of Essex. No part of this thesis has been submitted elsewhere for any other degree or qualification and, unless referenced to the contrary in the text, it is all the work of the author.

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There are many individuals who, in one way or another, have enabled me to complete this work. Listing everyone that has offered levels of professional support, personal encouragement and general motivation throughout my PhD would require several pages, however there are a few people who require a special mention.

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I would like to give a special thank you to Adi Lausen who has supported me on both a personal and professional level. I am appreciative of his time and knowledge that he has gifted to me, but most of all I am forever grateful for the level of empathy and friendship that he has consistently provided. I am sure that were it not for his vital encouragement and reassurance, I would have struggled to find the motivation that I needed to see this project through to completion.

Finally, I devote heartfelt thanks to my friends and family who have supported me throughout this research. There have been some tough times over the last few years but I will be eternally grateful for the continued love and understanding of my parents. Their constant belief in me has provided a consistent reminder of why I undertook this PhD. Although my grandparents did not get to fulfil their wish of seeing me complete my PhD, I know that they are looking down on me with immense pride.

Contents

List of Figures

List of Tables

1 Introduction

Chapter 1 Contents

1.1 Overview of the UK Education System

The UK education system will be referenced frequently throughout this thesis and so this subsection provides a general overview for the reader to gain familiarity with the education structure prior to formally introducing this research.

The four countries of the United Kingdom have their own curricula which are compulsory to be taught to students aged between 5 and 16: England follows the *National Curriculum*; Wales has recently introduced and is currently rolling out the *Curriculum for Wales*; Northern Ireland follows the *Northern Ireland Curriculum*; and Scotland follows the *Curriculum for Excellence*. The purposes of these curricula are to provide coherence in the subject content which students will learn with the aim that all students are educated with high standards of core knowledge which they will need for work and daily life (DfE, 2013). For more details about each of these curricula, see JMC (2020), House of Commons Library (2024) or Section D.1. Of particular relevance to this thesis are the options for study after the age of 16 which is discussed further in Section 3.3.1. Since the structure of the Curriculum for Excellence differs the most to the other curricula, when referring to the *UK* in relation to an education system throughout this thesis, we will implicitly exclude Scotland from this definition and refer solely to England, Wales and Northern Ireland for ease of reference unless otherwise stated.

This thesis will refer to four distinct levels of education that are relevant to the UK education system: *Primary Education*; *Secondary Education*; *Further Education*; and *Higher Education* (see Figure 1.1). These education levels are discussed in brief in this chapter, however further information about these education levels are discussed in DfE (2016). *Primary Education* will refer to compulsory education that takes place between the ages of 5-11 in a primary school. *Secondary Education* will refer to compulsory education that takes place between the ages of 11-16. *Further Education* will refer to formal education that takes place (typically) between the ages of 16 to 18. Some learners will study Secondary Education in an 11-16 school and then go on to a separate sixth form college or general further education college to study Further Education, whilst others learners will study both of these education levels in a single 11-18 school which includes a sixth form. *Higher Education* will refer to education studied at universities. The typical age for starting at university on an undergraduate course in the UK is 18, however most UK universities can accept students aged 16 and over. Most undergraduate degree courses last three years, however this may differ depending on the course itself, such as in the case of degrees offered with a foundation year, year abroad or placement year. In addition, there is usually an option for students to study a foundation year in Higher Education prior to starting their degree course (sometimes termed Year 0). The intention of a foundation year is to prepare students for their degree course in the event that they have failed to meet the minimum entry requirements of the course.

In addition to the levels of education noted above, there are also nine recognised levels of qualifications which can be obtained in the UK (UK Government, 2012). These are numbered reflecting their ascending level of difficulty and are summarised in brief in Table 1.1 and integrated in Figure 1.1.

Higher Education refers to education of Level 4 standard and above (see Table 1.1) and is typically offered by university institutions. Most commonly, students in Higher Education will study for either undergraduate (Level 6) or postgraduate (Level 7 and Level 8) degrees. In most UK university institutions, students who achieve a Level 6 undergraduate degree will be awarded a Bachelor's degree (most commonly in Arts [BA] or in Sciences [BSc]) with those who choose to go on to successfully study a Level 7 postgraduate degree being awarded a Master's degree (again, in Arts [MA] or in Sciences [MSc]). A Level 7 qualification can also include an undergraduate Master's degree (sometimes referred to as an *integrated Master's*) which is a longer course where students will study elements from both undergraduate Bachelor's and postgraduate Master's degree courses. This means that students will be awarded a Level 7 Master's qualification without needing to have obtained a Level 6 Bachelor's qualification first. Examples of this within the study of Mathematics include a Master's of Mathematics (MMath) or Master's in Science (MSci). In England, Wales and Northern Ireland, an undergraduate degree course in Higher Education generally comprises of three years of study, with the option to study a foundation year at some universities in certain circumstances:

Year 0: Alternatively called a *foundation year*, this is where students who have not met the minimum entry requirements will work towards meeting the necessary learning outcomes needed to enrol on their chosen degree course. Year 0 can be seen as a preparation year whilst allowing students to experience same types of university learning environments and teaching styles which they will meet on commencement of their degree course in Year 1.

Year 1: Students who have met the minimum entry requirements will start in Year 1. Students must pass this year in order to progress to the remainder of this course. Whilst the purpose of Year 1 may differ across university institutions, it is generally the case that

Table 1.1 | A summary of the nine levels of qualifications that can be obtained in the UK set out by the Regulated Qualifications Framework (RQF, (Ofqual, 2015)).

Note that this table contains an abridged list of example qualifications that are deemed to be most relevant to this research. For a full list of qualifications at each level, see UK Government (2012).

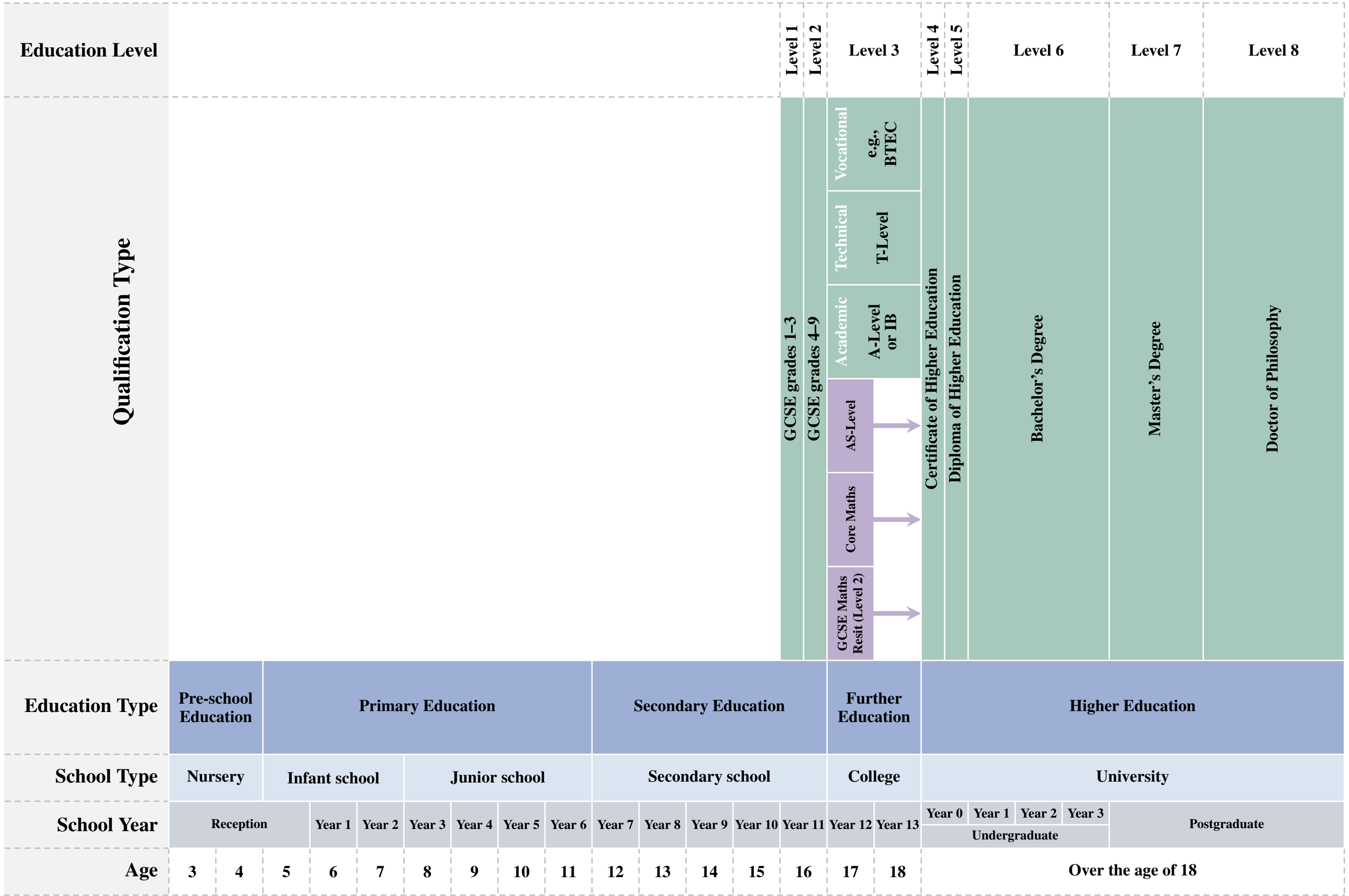
Level	**Example Qualifications**
Entry level	• Entry level languages • Entry level functional skills
Level 1	• GCSE grades 3,2,1/D,E,F,G
Level 2	• GCSE grades 9,8,7,6,5,4/A*,A,B,C
Level 3	• A-Level • AS-Level • Core Mathematics
Level 4	• Certificate of Higher Education
Level 5	• Diploma of Higher Education
Level 6	• Bachelor’s degree
Level 7	• Master’s degree • Post Graduate Certificate in Education (PGCE)
Level 8	• Doctor of Philosophy

it will ensure that a minimum level of knowledge is known prior to starting Year 2.

Year 2: Students will develop many of the concepts studied in Year 1 and the grades which students achieve in this year will constitute part of their overall degree classification.

Year 3: Students will complete their degree in this year where their grades from Year 2 and Year 3 will be aggregated to form their overall degree classification.

By contrast, Scotland has a markedly different Higher Education structure and is outlined in Section D.1.4. This thesis is investigating post-16 qualifications in relation to starting at university, and thus we will mostly use *Higher Education* in reference to a Level 6 undergraduate degree throughout this work.



Note: The *age* category specifies a student's age for the birthday during the school year. Qualification types which are shaded purple indicate additional mathematics qualifications alongside the other Further Education pathways. Some of these qualifications can be taken as a one- or two-year course and, particularly in the case of Core Mathematics and AS-Levels, can be taken in either Year 12 or Year 13. Core Mathematics and AS-Levels are, however, only available to those who are taking A-Levels as a post-16 option. The GCSE Mathematics resit is compulsory for students who have failed to obtain a pass grade (4 or above) at the end of Secondary Education.

Figure 1.1 | An overview of the Education system in England, Wales and Northern Ireland. In England, it is compulsory to study Primary Education, Secondary Education and Further Education (ages 4-18), however it is only compulsory to study mathematics until obtaining Level 2 GCSE Mathematics.

1.2 Relevance of this Research

The purpose of this research was to provide evidence of the predictors of mathematics ability of students in Higher Education, with the main focus on investigating the benefits of having a post-16 mathematics qualification when starting at university. There are three motivating reasons why this research is of relevance which are outlined below.

Firstly, the UK has a shortage of mathematics-based skills in Higher Education and industry when compared to other countries (Hodgen et al., 2010). In 2017, the Smith Review (A. Smith, 2017) produced major findings on post-16 mathematics in the UK education system which highlighted that the shortage of mathematics skills in the UK was partly due to mathematics ceasing to be compulsory to learners after the age of 16, despite students having to stay in education or employment training until the age of 18 in England. Negative associations towards mathematics among learners has arguably led to a high proportion of students in Further Education failing to choose to study any mathematics qualifications between the ages of 16-18. The Smith Review stated that this led to students lacking in confidence and experiencing high levels of anxiety, particularly when going on to study at university where they will likely need to rely on quantitative skills as part of their degree scheme. The target participants of this research were students studying in Higher Education which means that the work conducted in this thesis has aimed to gather evidence of many of the key issues raised immediately following the release of the Smith Review. The findings of this review are discussed in more detail in Section 3.6.

Secondly, the UK education system underwent major reforms in 2017 that changed the way that mathematics, among other subjects, were taught in Secondary Education and Further Education. Many of these changes are detailed in Section 3.1 and, in particular, we discuss the impact of these changes in relation to Higher Education and Industry. In brief, changes have included the introduction of harder topics to the mathematics curriculum in Secondary Education as well as standardisation to the mathematics curriculum in Further Education meaning that Higher Education and employers are more certain about the types of mathematics which learners with a mathematics qualification will have met (Advisory Committee on Mathematics Education (ACME), 2011; DfE, 2016). In addition to this, changes to the structure and grading of these qualifications have changed the way in which mathematics has been learnt in Secondary Edcuation and Further Education. At the start of conducting this research, it was still unclear among the education community what impact these major reforms to the education landscape would have on students when starting at university, thus we attempted to document evidence through the form of three studies over four years. Indeed, there is still surprisingly little evidence that attempts to document the shortage of mathematics skills in Higher Education, which is a research gap that this project aims to address.

Thirdly, post-16 mathematics qualifications were previously inaccessible to many learners due to their high entry requirements or the perception among many students that mathematics is hard or difficult. To partially address this, a new set of six post-16 mathematics qualifications termed *Core Mathematics* (DfE, 2013) were approved in December 2014 for first examination in 2016. These Level 3 qualifications were designed to prepare students for the mathematical contexts which they may meet in future work or Higher Education study by developing mathematical understanding and confidence. They are distinct from the aims of A-Level Mathematics, thus making them more accessible for a different set of learners such as those looking to study a degree course in social science fields (DfE, 2018). The purposes of Core Mathematics are summarised in more detail in Section 3.3.7, however the introduction of new post-16 mathematics qualifications need evidence that post-16 mathematics is indeed beneficial for learners, particularly when starting at university, which this research project aims to provide.

These motivating reasons are particularly relevant for students studying in Higher Education since there are a large number of degree schemes at university that involve some form of quantitative element. For instance, a Psychology degree is described as having a “significant amount of mathematics content” (A. Field, 2014) with other subjects such as Sociology, Sports Science or some Business degrees also involving a high level of quantitative skill. We calculated that approximately one-third of degree schemes and over half of the departments at our target institution for the three studies, the University of Essex, taught a quantitative module in the first year. We have summarised the types of content studied on these courses in Section D.2. We also need to consider that many of these degree courses do not require a post-16 mathematics qualification as part of their entry requirements, as well as the fact that an estimated 200 000 students in UK Further Education do not take any form of post-16 mathematics (Homer et al., 2020). As such, this leads to a high proportion of students starting on degree schemes at university without having studied any mathematics for at least two years. The Smith Review (A. Smith, 2017) stated that 40% of students on STEM degrees had not studied a post-16 mathematics qualification and this figure rises to 80% of students on non-STEM degrees. These same students are then expected to start on a university degree, likely with associated potential anxieties and lack of confidence with mathematics, and study quantitative modules that sometimes involve content that is also studied on a first-year degree in mathematics. Despite this obvious problem, there is surprisingly little research to show whether having a post-16 mathematics qualification is beneficial to students when starting at UK universities in helping to address some of these shortages in mathematics skills and helping to alleviate the problems arising with anxiety or lack of confidence. The three motivating reasons stated above justify why this work is of particular relevance now.

1.3 Research Aims

We conducted three studies in this research, of which the 2021-2022 Study and the 2022-2023 Study were pre-registered (Partner et al., 2021, 2022). We detail the main research questions and hypotheses in this section.

In response to the three main motivating reasons for conducting this research described in the previous subsection, this thesis has the following six Research Questions (RQ):

RQ 1: Is there a difference in the performance accuracy[1] between individuals that have been exposed to high levels of post-16 mathematics and those that have not at the beginning of the first term of university (pre-test)?

RQ 2: Is there a difference in the performance accuracy between individuals that have been exposed to high levels of post-16 mathematics and those that have not after a term

[1]We took *performance accuracy* to mean the ability to be able to determine the correct option from a set of multiple-choice answers in a given quantitative question.

of studying quantitative skills-based modules at university at the beginning of the second term of university (post-test)?

RQ 3: Is there a change in performance accuracy between the first and second term of university (pre- and post-test) between individuals that have been exposed to high levels of post-16 mathematics and those that have not?

RQ 4: Is there a difference in retrospective confidence judgments when answering mathematics skills questions between individuals that have been exposed to high levels of post-16 mathematics and those that have not?

RQ 5: Is there a difference in the levels of mathematics anxiety between individuals that have been exposed to high levels of post-16 mathematics and those that have not?

RQ 6: Do levels of individual personality traits predict performance accuracy, retrospective confidence judgments and mathematics anxiety?

We defined *high* levels of post-16 mathematics to correspond to participants that had directly studied a mathematics qualification between the ages of 16-18. Qualifications may be any one of AS-/A-Level Mathematics, Further Mathematics, Statistics or Core Mathematics, or an equivalent non-UK qualification. We defined *low* levels of post-16 mathematics to correspond to participants that had not studied an explicit mathematics qualification between the ages of 16-18. Some A-Level qualifications such as Chemistry and Geography, have a prescribed amount of quantitative content included as part of the assessment since the 2017 A-Level reforms (see Section 3.3.10 for more details on this). Whilst we did collect some demographic data in this direction as part of the work detailed in Chapter 6, we still chose to categorise these participants within the *low* levels of mathematics group on the basis that they were likely to have only met small amounts of mathematics in these specific contexts rather than building significant depth and understanding akin to the *high* levels of mathematics group who had studied an explicit post-16 mathematics qualification. Since our target participant population included participants that had studied post-16 qualifications in the UK and those that had not, we asked participants whether they were in full-time education in England, Wales or Northern Ireland between the ages of 16-18. We then asked participants whether they had studied a mathematics qualification during these ages. For students that had studied a post-16 mathematics qualifications in the UK, we asked them to select which mathematics qualifications they had studied from a given list of qualifications (e.g., AS-/A-Level Mathematics, IB Mathematics, Core Mathematics).

In order to answer these research questions, a study protocol needed to be developed which addressed the following two research aims:

1. To determine the main predictors of performance accuracy in mathematics-based tasks at university.
2. To determine the impact which one term of studying at university has on performance accuracy in mathematics-based tasks.

We formed a total of 13 sub hypotheses which aligned to four main hypotheses groups according to the variables using the Research Questions (RQ) and was developed after a literature review had been conducted:

Hypothesis 1: Performance accuracy in numeracy and statistics tests.

H1a: Participants who have been exposed to high levels of post-16 mathematics will have higher performance accuracy on numeracy and statistics tests than those who have been exposed to low levels of post-16 mathematics at the pre-test. **[RQ 1]**

H1b: Participants who have been exposed to high levels of post-16 mathematics will have higher performance accuracy on numeracy and statistics tests than those who have been exposed to low levels of post-16 mathematics at the post-test. **[RQ 2]**

H1c: Participants who have been exposed to low levels of post-16 mathematics will show a higher level of improvement on performance accuracy on numeracy and statistics tests between the pre-test and the post-test than those who have been exposed to high levels of post-16 mathematics. **[RQ 3]**

Hypothesis 2: Retrospective confidence judgments.

H2a: Participants who have been exposed to high levels of post-16 mathematics will rate themselves more often as “I am quite confident” or “I am very confident” on retrospective confidence judgements when answering numeracy and statistics questions compared to participants who have been exposed to low levels of post-16 mathematics at the post-test. **[RQ 4]**

H2b: Participants who rated themselves as “I am guessing” or “I am not confident” will have a low performance accuracy on numeracy and statistics questions compared to participants who rated themselves as “I am quite confident” or “I am very confident” at the pre-test. **[RQ 1/4]**

Hypothesis 3: Mathematics anxiety.

H3a: Participants who have been exposed to low levels of post-16 mathematics will show a higher level of mathematics anxiety than who have been exposed to high levels of post-16 mathematics at the pre-test. **[RQ 5]**

H3b: Participants with high levels of mathematics anxiety will have low performance accuracy on numeracy and statistics tests compared with participants with low levels of mathematics anxiety at the pre-test. **[RQ 1/5]**

H3c: Participants with high levels of mathematics anxiety will rate themselves more often as “I am guessing” or “I am not confident” on retrospective confidence judgements compared with participants with low levels of mathematics anxiety at the pre-test. **[RQ 4/5]**

Hypothesis 4: Personality traits.

H4a: Participants with high levels of the conscientiousness trait will exhibit high levels of performance accuracy at the pre-test. **[RQ 1/6]**

H4b: Participants with high levels of the openness trait will exhibit high levels of performance accuracy at the pre-test. **[RQ 1/6]**

H4c: Participants with high levels of the neuroticism trait will exhibit low levels of performance accuracy at the pre-test. **[RQ 1/6]**

H4d: Participants with high levels of the neuroticism trait will exhibit high levels of mathematics anxiety at the pre-test. **[RQ 5/6]**

H4e: Participants with high levels of the agreeableness trait will show high levels of improvement in performance accuracy between the pre-test and the post-test. **[RQ 3/6]**

In addition to conducting research that investigated the above-mentioned research questions, this work also produced a survey tool that could act as a diagnostic for ability in mathematics-based tasks at the start of university degree courses (pre-test) and after approximately one term of university teaching (post-test). This included developing a bespoke set of questions that could determine ability in a set of key mathematical skill areas and could sit alongside standard instruments that were used to measure a participant's level of confidence, mathematics anxiety, attitudes towards mathematics, personality traits and perceived level of impact regarding COVID-19 on a participant's education. Whilst other diagnostic tools may exist to determine standalone measures, the intention is that this tool has been developed specifically to monitor students as they enter university education and we have demonstrated its capability through the three studies that we have conducted.

Immediately after the 2019-2020 study was concluded in March 2020 the COVID-19 pandemic majorly affected the UK. This meant that some of the study protocol that had previously been used had to be redesigned and resulted in an online only study being conducted in 2021-2022. The COVID-19 pandemic had an adverse affect on the education system disrupting many of the assessments and ways in which lessons had to be conducted. This presented us with a unique opportunity to provide a snapshot of the repercussions of these disruptions in relation to students starting at university immediately after the height of the pandemic. We then conducted a final study in 2022-2023 which was a hybrid study consisting of a lab-based face-to-face study conducted at the University of Essex and an online-based remote study which was conducted at 14 other university institutions. This data was collected when most of the UK had returned to a relative normal with regards to COVID-19 which allowed us to capture data after the COVID-19 pandemic. This meant that our research questions could be adapted to include the perceived effect of COVID-19 on a participant's education.

1.4 The Research Process

There was an identified need for research that gathered evidence into the effects of post-16 mathematics qualifications in relation to performance accuracy on mathematics-based tasks in Higher Education, however there was also a need to explore additional factors that may contribute to differences in performance accuracy levels.

This research consisted of three studies that took place at the start of each university academic year. The first study described in Chapter 4 was conducted between October 2019 and February 2020 and was used to inform which predictors may give insight into academic performance at university. The second study described in Chapter 5 was conducted between October 2021 and February 2022 and was used to monitor the impact of COVID-19 on a participant's education. The third study described in Chapter 6 was conducted between October 2022 and February 2023 and was used to inform about education experience in relation to academic performance.

The research process consisted of the following five stages:

1. **Identify the predictors that could be used for academic performance.**
   (a) Conduct a literature review.
   (b) Plan the first study.
2. **2019-2020 Study.**
   (a) Gain support from departments to recruit participants.
   (b) Conduct the pre-test.
   (c) Conduct the post-test.
   (d) Conduct the data analysis.

3. **2021-2022 Study.**
    (a) Adapt the study design to allow the survey to be taken online as opposed to a lab.
    (b) Pre-register study design protocol.
    (c) Recruit participants through departmental contacts.
    (d) Conduct the pre-test.
    (e) Conduct the post-test.
    (f) Conduct the data analysis.
4. **2022-2023 Study.**
    (a) Adapt the study design to allow the survey to be taken both online and in a lab.
    (b) Pre-register study design protocol.
    (c) Recruit participants.
    (d) Conduct the pre-test.
    (e) Conduct the post-test.
    (f) Conduct the data analysis.
5. **Interpret the findings.**
    (a) Consider how post-16 mathematics qualifications affect performance accuracy in mathematics tasks.
    (b) Consider the important predictors of performance accuracy in mathematics tasks at university.

In order to investigate our research questions and associated hypotheses, we implemented the following analysis plan for each of our studies:

1. **Test for normality.**
   We initially tested for the assumption of normality in order to determine whether to use parametric tests for our primary and secondary analyses or whether to use a more conservative non-parametric approach. We achieved this by using a Shapiro-Wilk test as well as visual inspection of histograms and measuring skewness and kurtosis.

2. **Primary and secondary analysis.**

   Depending on the outcome from analysis stage 1, we used difference and correlation tests to analyse our research hypotheses. This followed pre-registered analysis for the 2021-2022 Study and the 2022-2023 Study.

3. **Exploratory analysis.**

   We followed analysis stage 2 with further investigation of how our measured variables might predict numeracy and statistics performance that was in addition to our pre-registered analysis. We mainly achieved this using exploratory path analysis models to determine the direction and strength of the relationship between the factors based on our proposed hypotheses in Section 1.3.

1.5 Study Participants

Data was collected from a total of 605 foundation- and first-year undergraduate students at UK universities using three studies across separate years. Data from all three studies was collected from participants studying at the University of Essex, and the 2022-2023 Study also collected data from participants at 14 other UK universities. We aimed to recruit participants from departments that would study a quantitative module in the first term between the pre-test and the post-test. For the purposes of this study, we defined *quantitative* broadly as *"mathematical skills that involve numeracy, statistics and data analysis"* which is in line with the definition also used in the Smith Review (A. Smith, 2017). By considering degree schemes and their respective modules, we calculated that approximately one-third of all degrees at the University of Essex taught a quantitative module in their first year (see Section D.2).

The 2019-2020 Study (Chapter 4) recruited participants from the University of Essex who were mainly studying for a Psychology degree in addition to a small number of participants studying for a Mathematics degree and foundation year students studying in preparation for Economics and Business degrees. All participants attended voluntary lab sessions which were scheduled on their timetable for both the pre-test and the post-test. Participants completed the survey under the supervision of research assistants. This study was not pre-registered.

The 2021-2022 Study (Chapter 5) recruited participants from a range of departments at the University of Essex. This study was conducted online due to university guidance and uncertainty about COVID-19 preventing lab sessions taking place, so participants were recruited exclusively by emails sent by staff in their respective departments. This meant that students on the appropriate email lists were given instructions with a link to complete the pre-test. Since the survey was completed online, completion was not able to be supervised by research assistants. Participants were invited back to complete the post-test based on the university email address which they provided at the pre-test. This study was pre-registered.

The 2022-2023 Study (Chapter 6) was a hybrid study consisting of (1) participants who were recruited at the University of Essex and completed the survey in a scheduled lab session under the supervision of research assistants, and (2) participants who were recruited from external universities and completed the survey online in a similar manner to the 2021-2022 Study. Participants from the University of Essex were recruited using flyers handed out to students on the campus grounds and by advertising at the start or end of targetted lectures with the lecturers' approval. Since the method of recruitment at the University of Essex meant that we were less specific than the previous two studies in that we could not exclusively target recruitment to participants from departments which taught quantitative modules in their first term, we elected to use any participants who were not on quantitative degree schemes to control for differences between the pre-test and the post-test. Participants from other UK universities were emailed a link by staff in their respective departments in a similar manner to the recruitment from the 2021-2022 Study. All participants were invited back to complete the post-test using the university email address which they provided at the pre-test. Due to the hybrid nature of the 2022-2023 Study, we demonstrated that the survey could be administered both online and in a lab environment. This study was pre-registered.

1.6 Development of the Study Materials

As this work naturally progressed, we attempted to develop and improve the study materials and procedures. This also included limiting the impact of COVID-19 by using both lab and online data collection methods and adapting questions and instruments accordingly. Table 1.2 provides a broad overview of the materials and procedures that were used in each study and we attempt to provide rationale for these changes below.

The original intention of this work was to collect evidence through the form of a pilot study consisting of a small number of departments before using this to inform the design of a main study conducted in the following year with a larger number of departments. However, the impact of COVID-19 shortly after the conclusion of the 2019-2020 Study meant that we had to adapt our study methodology to the form now presented in this work. In particular, the original pilot study (now referred to as the 2019-2020 Study) was not pre-registered on the basis that the results from this were intended to form the basis of our hypotheses and analysis plan for the larger main study. The 2021-2022 Study and 2022-2023 Study were both pre-registered which were informed by the results and methodology of the previous studies. The primary and secondary analysis of these two studies followed a detailed pre-registered analysis plan, with exploratory analysis that went further than the plan outlined in the pre-registration.

As well as changes to whether the study was conducted in a lab, online or a hybrid of both, the method of recruitment naturally had to change to reflect this. In particular, the 2019-2020 Study recruited participants using sessions that appeared on their timetable with the intention that this would maximise the recruitment of potential participants. However, this also created complications in that participants were unable to be confidently matched between the pre- and post-test (see Section 4.1.2). We resolved these complications in the 2021-2022 Study which recruited participants through email communication given by departments and each participant's university email was used as an identifier when collecting consent. This meant that we only contacted participants at the post-test who had also completed the pre-test. A similar method of recruitment and email identification was used for the 2022-2023 Study, with the exception that recruitment for the lab-based element of this study involved lecture announcements and fliers.

The demographic questions remained broadly unchanged across all three studies, with the exception that additional education data was collected in the 2022-2023 Study. This related to data about non-mathematics post-16 subjects that a participant had studied as well as grades

Table 1.2 | Summary of the key features in each of the three studies for comparison purposes.

	2019-2020 Study	**2021-2022 Study**	**2022-2023 Study**
Pre-registration Status	Not pre-registered.	Pre-registered, including analysis plan that was followed (Partner et al., 2021)	Pre-registered, including analysis plan that was followed (Partner et al., 2022)
Recruitment	Timetabled teaching events.	Email communication via departments.	**Lab:** lecture advertisements and fliers. **Online:** email communication via departments.
Demographic	• Degree course • Age • Gender • Post-16 UK study • Post-16 maths quals. • Foundation year	• Degree course • Age • Gender • Post-16 UK study • Post-16 maths quals. • Foundation year	• Degree course • Age • Gender • Post-16 UK study • Post-16 maths quals. • Foundation year • Other post-16 subjects • Post-16 quals. grades
Numeracy Questions	19 pre-test 20 post-test *8 questions used at both pre- and post-test selected for analysis.*	15 pre-test 15 post-test *Different questions asked at post-test compared to pre-test. All questions used for analysis.*	8 pre-test 8 post-test *Different questions asked at post-test compared to pre-test. All questions used for analysis.*
Statistics Questions	10 pre-test 15 post-test *8 questions used at both pre- and post-test selected for analysis.*	15 pre-test 15 post-test *Different questions asked at post-test compared to pre-test. All questions used for analysis.*	8 pre-test 8 post-test *Different questions asked at post-test compared to pre-test. All questions used for analysis.*
Confidence	11-point Likert.	4-point Likert.	4-point Likert.
Personality	60-item BFI-2	Not measured.	30-item BFI-2-S
Subjective Numeracy	8-item SNS	Not measured.	8-item SNS
Mathematics Anxiety	13-item AEMAS	13-item AEMAS	13-item AEMAS
Mathematics Attitudes	Not measured.	Not measured.	19-item Short-ATMI
COVID-19	Not measured.	5-items (pre-test) 2-items (post-test)	5-items (pre-test) 2-items (post-test)

Quals. = Qualifications, *BFI* = Big-Five Personality Inventory (Soto & John, 2017a), *SNS* = Subjective Numeracy Scale (Fagerlin et al., 2007), *AEMAS* = Adult Everyday Mathematics Anxiety Scale (Rolison et al., 2016), *Short-ATMI* = Short Attitudes Towards Mathematics Inventory (Lim & Chapman, 2013).

obtained. Whilst we did not use this extra data within the analysis presented in this work in order to keep the analysis relatively consistent across the three studies, it could form the basis of further exploration.

The numeracy and statistics questions changed between the 2019-2020 Study and subsequent studies both in the number of items and the questions themselves. This was to accommodate the online component of the 2021-2022 Study and the 2022-2023 Study which forced us to review whether questions could easily be answered with potential access to external resources such as computer algebra systems or calculators. More detail describing these changes is given in Section 5.2.1 and Section 6.2.1. Due to the 2021-2022 Study being conducted entirely online we decided to increase the number of questions to 15 numeracy and 15 statistics questions to for this study in order to control for the fact that participants might access external resources. We then selected eight numeracy and eight statistics questions for the subsequent 2022-2023 Study using the results of the 2021-2022 Study to drive this selection method and is discussed in more detail in Section 6.2.1. The rationale for fewer numeracy and statistics questions in the 2022-2023 Study was that the questions had already been successfully tested in an online environment with the previous study and the fact that we included more instruments (described below). Additionally, in an effort to reduce learning effect of remembering answers, we designed a different set of numeracy and statistics questions for the post-test compared to the pre-test in the 2021-2022 Study and 2022-2023 Study. Each respective question in the post-test tested identical skills and was pitched at the same intended ability level to the related question that was asked in the pre-test.

Confidence judgments for the 2019-2020 Study were measured using a 11-point Likert (0 = *not at all confident*, 10 = *very confident*). This was changed in the subsequent studies to a four-point Likert scale with specific descriptors corresponding to each score (1 = *I am guessing*, 2 = *I am not confident*, 3 = *I am quite confident*, 4 = *I am very confident*), respectively. The rationale for this change was to make it easier to determine thresholds for confidence levels with the four-point scale naturally forming in a score of 1 or 2 as *low confidence* and a score of 3 or 4 as *high confidence*. An explicit score was also assigned for a participant to indicate that they were guessing an answer (i.e., 1 = *I am guessing*) and, thus, a resulting correct answer would likely be as a result of chance rather than judgement. Whilst we did not choose to analyse this data further in the work presented here, having the ability to determine this fact may give further insight into identifying which skill areas particular groups of participants were more likely to guess. Additionally, we decided that this was important to include this if making this tool available for wider use.

The personality instrument (Big Five Inventory 2, BFI-2) was not administered in the 2021-2022 Study on the basis that we were concerned about administering this in an online environment and the increased potential of participants prematurely ending their survey attempt due to boredom or fatigue. As such, we aimed to keep the survey short by removing the BFI-2. For the same reason we also removed the Subjective Numeracy Scale (SNS) from this study. The SNS and the BFI-2 were administered in the 2022-2023 Study, however we elected to use the shorter 30-item BFI-2-S (Soto & John, 2017b) here to again reduce the likelihood of online participants ending the survey prematurely.

We elected to include the Short Attitudes Towards Mathematics Inventory (Short ATMI, Lim & Chapman, 2013) in the 2022-2023 Study in order to give further insight of differences between groups with and without post-16 mathematics qualification. We did not include this within the prior studies simply because of challenges associated with collecting data for the first time (2019-2020 Study) and collecting data in an online environment and needing to create a survey that was sufficiently short (2021-2022 Study).

Finally, we asked questions about perceptions of COVID-19 and its impact on a participant's education. This could not have been forecast in the 2019-2020 Study and we saw it as an opportune moment to collect this data at a time during (2021-2022 Study) and after (2022-2023 Study) the pandemic. Whilst there have since been several viable instruments that have been developed to measure the perceived educational impact of COVID-19 (e.g., Voitsidis et al., 2021), at the time of conducting our studies we did not find one that both aligned with our research aims and was suited for use on our participants and so we elected to develop our own. The questions that we created aligned to the perceived impact as reported in the media and anecdotally by students, teachers and lecturers.

1.7 Outline of the Thesis

This thesis consists of three studies which were conducted with four cohorts of students. These three studies coincided with the COVID-19 pandemic and so we collected data prior to (2019-2020 Study), during (2021-2022 Study) and immediately after (2022-2023 Study) the pandemic. In this subsection, we describe the thesis structure.

In this chapter, Chapter 1, we provide an overview of the motivation for conducting this research. We outline key definitions, aims and explain the research process. In Chapter 2, we summarise the relevant literature which is pertinent to predictors of mathematical performance in Higher Education. In Chapter 3, we provide an overview of the post-16 mathematics pathways in the UK. In particular, we review some major reforms which have influenced the current education system as well as the broad post-16 mathematics qualifications which are currently and have previously been available to learners in 16-18 education. We also investigate the role which universities have in encouraging the uptake of post-16 subjects and whether mathematics and quantitative skills are important to universities. The 2017 Smith Review is also outlined in this chapter which was a motivating reason for conducting this research.

In Chapter 4, Chapter 5 and Chapter 6, we describe the 2019-2020, 2021-2022 and 2022-2023 Studies, respectively. Each chapter contains methodology detailing the aims of the study as well as the choice of questions and an explanation of the data collection process. This is then followed by the results of the data analysis and a discussion for the implications of our findings for quantitative performance in Higher Education in each chapter.

Finally, Chapter 7 integrates the findings of the three studies to offer an overview of how post-16 mathematics and other predictors of quantitative performance affects students starting on undergraduate degree courses in Higher Education.

1.8 Summary of Key Definitions

Throughout this thesis, we will use specific terms with definitions that have been altered for the purposes of this work. Some of these definitions and the reasoning for using them have already been discussed in Chapter 1, however a complete summary of important definitions are summarised in Table 1.3 for ease of reference.

Table 1.3 | A summary of key terms and their specific definitions which we will use throughout this thesis. Note that some of these terms have been redefined for the purposes of this thesis.

Key Term	Definition
A-Level	A two-year post-16 course which is a popular 16-18 academic pathway in the UK with almost 300 000 students enrolling each year (UK Government, 2022). Students will typically choose A-Levels in three subjects as this is the requirements for most university courses.
AS-Level	A one-year post-16 course which is equivalent in UCAS points to half an A-Level. Students can choose to acquire an AS-Level after the first year of their A-Level course.
Core Mathematics	An umbrella term which refers to a set of post-16 qualifications that can be studied alongside A-Levels. These are equivalent in UCAS points to an AS-Level. Examples of Core Mathematics qualifications include *Mathematics in Context* (Edexcel), *Quantitative Reasoning and Problem Solving* (OCR MEI), *Mathematical Studies* (AQA), *Using and Applying Mathematics* (City & Guilds) and *Mathematics for Work and Life* (Eduqas).
Foundation Year	A Year 0 which is sometimes taken by university students prior to formally starting their chosen degree course.
Further Education	Education of Level 3 standard studied between the ages of 16-18, in particular AS-/A-Levels.
Higher Education	An undergraduate degree of Level 6.
International Baccalaureate (IB)	A two-year post-16 course which is an alternative 16-18 academic pathway to A-Levels. The IB is an internationally recognised course which typically involves study of five subject areas including mathematics.
Level 3 [Qualification]	A post-16 qualification standard that includes AS-/A-Levels and IB qualifications (see Table 1.1).
Post-16 [Education]	See Further Education.
Quantitative	Mathematical skills that involve numeracy, statistics and data analysis.
UK [Education]	When referring to the UK education or UK students, we will refer to England, Wales and Northern Ireland *only* (excludes Scotland), unless otherwise stated.

2 Literature Review

Chapter 2 Contents

This chapter will provide an overview of the current literature relevant to UK mathematics education that motivated this research. Specifically, we review the main predictors for mathematics performance in Higher Education that were chosen for this work as demographics, personality, mathematics anxiety and confidence judgments. The studies that were identified for review came from fields of mathematics and statistics education as well as psychology and educational psychology. Some of the areas for review such as mathematics anxiety, confidence judgments and personality are broad-ranging and, as such, we elected to focus specifically on their association with mathematics performance. The amount of literature in these areas that was specific to the UK was limited, so we also included studies from other countries to demonstrate the current understanding in these research fields.

Whilst we did not seek to conduct a systematic literature review, we did aim to describe the scope of the mathematics education research that has explored factors relating to quantitative performance. We primarily searched for the relevant literature by using keyword searches that were related to each specific research question and prioritised results that were published recently or were conducted within the UK or Higher Education. In addition, we identified specific journals and authors when filtering search results that we further used to search for relevant results. We also used the references of potential sources to find additional results from the citing literature. Each source was individually screened using the title, keywords, and abstract and, if a source was deemed to be relevant, a brief synopsis was created that summarised its aims, study methodology (if appropriate), and relevant results. General themes were established according to factors that predicted quantitative performance and the literature was compared within each theme according to the findings, implications, inconsistencies, data analysis, and methodology. Some literature, such as reports published by the Department for Education, did not align exactly to this approach and so required additional keyword searches of the databases available via the UK Government website.

The research design was conducted in three phases with an exploratory lab-based study looking at the predictors of performance in UK Higher Education (Chapter 4), an online study that was conducted 18 months after COVID-19 first hit the UK and at which time UK education had been majorly disrupted (Chapter 5), and a hybrid study that was lab-based and online which explored previous educational experience and its role in predicting performance in UK Higher Education (Chapter 6). These three aims meant that the choice of design differed slightly for each study. For example, the lab-based studies meant that participants would be more willing to complete a survey that could last up to an hour in duration and so we could afford to take additional measurements such as personality and subjective numeracy. This meant that the literature could provide insights into these areas. The online study needed to be shorter in duration and so the emphasis was placed on the numeracy and statistics questions, confidence and maths anxiety, which the literature helped to direct.

This chapter starts by (1) the shortage of mathematics skills in Higher Education and industry specific to the UK and demographic factors of mathematics performance (Section 2.1), (2) mathematics anxiety and its effect on mathematics performance (Section 2.2), (3) confidence judgments and attitudes and their effect on mathematics performance (Section 2.3), and (4) personality and its effect on mathematics performance (Section 2.4).

2.1 Shortage of mathematics skills in Higher Education and industry specific to the UK

The UK is reported to have one of the lowest uptakes of post-16 mathematics with some estimates such as that by Hodgen & Marks (2013) putting post-16 mathematics participation as low as 20%, with only 13% of 16- to 18-year-olds studying advanced mathematics such as A-Level Mathematics. Compare this to more than 50% of students studying post-16 mathematics in other countries such as Australia, Canada, France, Germany and the USA (Hodgen et al., 2010), the UK clearly has a shortage in this vital skillset. This has implications for Higher Education where 40% of UK students on STEM degrees and 80% of UK students on non-STEM degrees have not studied any form of mathematics after it ceases to become compulsory (A. Smith, 2017). Indeed, this "mathematics gap" (DfE, 2013) caused by students forgetting or losing vital numeracy skills by not studying mathematics between the ages of 16-18 is far-reaching in many areas of industry as well as Higher Education (Dalby & Noyes, 2016; Hodgen & Marks, 2013; A. Smith, 2017). This shortage of school leavers who are equipped with the core mathematical skills to engage in a modern, data-driven and scientific society, exacerbated by learners choosing to discontinue with studying mathematics after the age of 18, is reported to have negative implications for the wider economy (ACME, 2011; British Academy, 2012, 2015; Mason et al., 2015). For example, National Numeracy (2019) found that 75% of adults in their samples were not functionally numerate, and claimed that half of UK adults had the same level of numeracy as a primary school child. In addition, they stated that this low level of numeracy among working adults was estimated to cost the UK economy £20 billion per year. This lack of post-16 mathematics among large swathes of students also impacts Higher Education, with evidence showing that undergraduates are generally unprepared in dealing with the mathematical demands of certain degree courses with quantitative elements (Hodgen et al., 2014, 2020).

Mathematics and its associated skill shortages within school-leavers is a priority concern, with prominent members of government such as the former Secretary of State for Education, Michael Gove, and the Prime Minister, Rishi Sunak, among those promoting the case for mathematics education until the age of 18 (DfE, 2011; UK Government, 2023e). In a step towards this, the influential Wolf Report (Wolf, 2011) led to it being made compulsory for students that failed to obtain a pass grade in GCSE Mathematics to retake the qualification since 2014. This currently means that around 180 000 students in England who fail to reach a grade 4 or above in GCSE Mathematics each year are required to continue studying mathematics alongside their chosen post-16 education pathways in order to obtain a Level 2 qualification in the subject by the age of 18 (Education and Skills Funding Agency, 2014b; Vidal Rodeiro, 2018; Norris & Noyes, 2023).

In 2015 the UK reformed many aspects of its education system to ensure that functional skills and problem solving were incorporated as a greater proportion of the mathematics syllabus (Ofqual, 2019). Major changes were made to GCSE Mathematics, partly with the aim to improve the transition into post-16 mathematics which was historically reported as being challenging due to the difference in difficulty, particularly when compared with other subjects (Wiliam et al., 1999; Mendick, 2008; Noyes & Sealey, 2012; Hernandez-Martinez et al., 2011). Changes were also implemented to the structure and syllabus of A-Level Mathematics such as a greater emphasis on mathematical thinking and modelling as well as the prescription of applied statistics and mechanics content in order for university departments to be more certain about the types of mathematics which a typical student will have met (ALCAB, 2014; DfE, 2016; Glaister, 2017a). Despite this, these reforms have been greeted with criticism regarding their effectiveness. For example, several established bodies have called for the compulsory GCSE Mathematics retake policy to be reevaluated, citing that students tend to become demotivated with mathematics after repeated attempts and suggested that alternative mathematics qualifications which better-aligned to their chosen post-16 options should be offered instead (Ofsted, 2015; NAHT, 2017). Reports also showed that learners forced to retake GCSE Mathematics in

Further Education had less motivation in the subject (ETF, 2014) and that embedding mathematics within existing post-16 courses can encourage students to positively change their beliefs about the perceived usefulness (Dalby & Noyes, 2016).

There are several reasons why students choose to take A-Level Mathematics. For example, the feeling of enjoyment coupled with being successful in the subject is an important factor (Brown et al., 2008; Noyes & Sealey, 2012). However, being successful at GCSE Mathematics does not necessarily equate to choosing to continue studying the subject after it ceases to become compulsory.

As such, it has been argued that additional post-16 mathematics pathways such as the recently introduced Core Mathematics (DfE, 2013) should be made available in order to address the estimated 200 000 students failing to take post-compulsory mathematics each year (Homer et al., 2020). Whilst Core Mathematics has been welcomed by many (Glaister, 2017b; The Royal Society, 2022), The Royal Society (2023) found that less than a third of state-funded Further Education schools and colleges had students taking a Core Mathematics qualification in 2022. Moreover, it was also reported that the provisions of Core Mathematics across England was unevenly spread, with around 10% of local authorities not having any students taking Core Mathematics. Homer et al. (2020) gave some context to this by highlighting that the uptake of Core Mathematics has been faced with various challenges. Among which was the lack of recognition from Higher Education which made it harder for Further Education schools and colleges to justify providing this additional qualification alongside the traditional A-Level programme. This was further evidenced by Glaister (2015b) who published statements about Core Mathematics and their relevance for Higher Education that were voluntarily provided to him by a number of universities. These statements were given in response to institution-wide communications to Vice Chancellors from the Minister of State for Schools and the Minister of State for Universities and Science, with a briefing paper and the offer for briefings visits to raise awareness of the Core Mathematics qualifications (Glaister, 2015a). Only a few universities such as Bath, Exeter, Keale, Sheffield and York reduced their entry requirements for students with a Core Mathematics qualification. Arguably, this has meant that the number of students taking

Core Mathematics has plateaued since 2020 with around 12 000 entries for each year since. The limitations of Core Mathematics and many of the broad post-16 pathways which are currently available to learners in Further Education are described in further detail in Section 3.3, along with their feasibility for increasing the numbers of students looking to take post-compulsory mathematics.

Higher Education must also recognise the role which it plays in encouraging students to take post-16 subjects. Evidence shows that students need to be considerate about the post-16 subjects which they choose as this can affect the degree scheme, or even the university they can study at (Vidal Rodeiro et al., 2013, 2015; S. Smith et al., 2015; Hupkau et al., 2017). For example, Dilnot (2018) found that A-Level Mathematics was a "facilitating subject" meaning that it was more positively associated with gaining a place at top-ranking universities since they viewed the subject as good preparation for their courses. To complement this, Vidal Rodeiro & Sutch (2013) utilised data obtained from the Universities and Colleges Admissions Service (UCAS) and found that A-Level Mathematics was the most popular A-Level subject taken by students attending Russell Group universities with 50.9% of students accepted to this group of universities taking the subject. The authors also demonstrated that good grades in A-Level Mathematics were correlated with securing a place at university with 51.6% of accepted students achieving a grade A or A* in A-Level Mathematics which was the one of the highest acceptance rates of any A-Level subject. This shows that A-Level Mathematics is viewed favourably by Higher Education and is a strong choice for students considering studying at university. Whilst the evidence suggests that studying A-Level Mathematics is positive for future university prospects, it should be noted, however, that the ability to take post-16 subjects such as mathematics is dependent on a variety of factors such as high attainment in GCSE Mathematics, which may in turn may be affected by socio-economic background (Vidal Rodeiro, 2007; Dilnot, 2016; Codiroli Mcmaster, 2017; Gill, 2017). Indeed, the Smith Review reported ethnic differences with Asian students achieving higher GCSE grades than white students as well as geographic (a higher proportion of students in London study A-Level Mathematics compared to the North East of England) and gender (approximately 60% of A-Level Mathematics students are male) differences (A. Smith, 2017). However, even when controlling for background characteristics, studies have shown that the post-16 subjects which students choose to take remains one of the most important factors when progressing to pathways beyond Further Education such as university (S. Smith et al., 2015; Hupkau et al., 2017; Dilnot, 2018).

Evidence shows that mathematics and statistics skills permeate a wide range of degree courses (Koenig, 2011; Buckley et al., 2015; Darlington & Bowyer, 2016, 2017) with most universities requiring that applicants have a minimum of a pass grade (grade 4/C) in GCSE Mathematics (Hodgen et al., 2014). Indeed, A. Field (2014) described a Psychology degree as having "significant mathematics", highlighting the fact that most universities which taught a degree in Psychology did not require a mathematics qualification beyond GCSE. Likewise, Dawson (2014) raised a similar concern regarding Economics degrees, citing that A-Level Economics did little to prepare students for the quantitative demands of the subject at university. The author also noted that some universities had to stream students into cohorts based on their previous mathematics background to ensure that mathematics content could be taught effectively, whilst other universities specified that A-Level Mathematics was a required subject for applicants. Nevertheless, this evidence questions whether universities are effectively communicating the mathematics and statistics requirements of a degree course to prospective applicants. Lee et al. (2017) summarised UCAS data which showed that 22 UK universities each accepted more than 1000 students with an A-Level Mathematics in 2016, rising to 39 universities each accepting more than 500 students with A-Level Mathematics in the same year. The authors also found that of the 757 non-mathematics degree courses that they surveyed, 56% of them required A-Level Mathematics. This implies that if a degree course requires a post-16 mathematics qualification such as A-Level Mathematics, then students will be clear about the quantitative demands of that particular degree subject. However, Hodgen et al. (2014) argued that the lack of messaging to prospective students about the quantitative demands of their degree courses meant that students were often left unprepared with regards to expectations prior to starting the course. This was also evidenced in a sample of undergraduates on economics degrees where 81% of respondents stated that they were surprised by the amount of mathematics content with some students retrospectively stating that they would have chosen to do A-Level Mathematics if they had been better informed about the quantitative demands of their course (Economics Network, 2012). As such, several reports made the strong recommendation that Higher Education should have a better understanding of the capabilities of prospective undergraduate students aided by improved communication about their expectations, particularly with regards to the quantitative demands of particular degree schemes (ACME, 2011; Dawson 2014; Hodgen et al. 2014).

Predicting mathematics performance within Higher Education has been of interest for several decades (Greer & Semrau, 1984; Mulhern & Wylie, 2004; Durrani & Tariq, 2012; Thompson et al., 2015) with evidence highlighting that the skills shortage is greater for mathematics than other subjects. Indeed, some studies have even suggested a gradual decline in the mathematics abilities of applicants. For instance, Mulhern & Wylie (2004) demonstrated that cohorts of Psychology students entering university a decade apart demonstrated a clear decline in their quantitative performance. However, since the authors were using the same numeracy test as Greer & Semrau (1984), they found that this trend of declining mathematics-based performance actually continued back further to Greer & Semrau's study from 1984. Hence, given the recent reforms to the UK education landscape, it is necessary to understand whether this trend continues to the present day.

Thompson et al. (2015) in their study of undergraduate students from multiple universities highlighted that previous mathematics grades (such as those received in GCSE and A-Level qualifications) were a significant predictor of mathematics performance when entering university. However, when individuals enter university they have a general scope of knowledge learned from studying GCSE and A-Level subjects. This knowledge is then honed to a specific degree subject and so by the end of their degree they have specialist knowledge which is directly relevant to their chosen degree. Indeed, these effects of previous mathematics qualifications are cited as being stronger for predicting poor mathematics performance at the start of a degree course (Greer & Semrau, 1984; Mulhern & Wylie, 2004; Thompson et al., 2015) than towards the final stages (Adkins & Noyes, 2018). Despite this, previous mathematics qualifications are still of relevance as this may promote better transitions between Further Education and Higher Education (Hernandez-Martinez et al., 2011).

2.2 Mathematics anxiety and its relationship with mathematics performance

Whilst demographic factors such as previous mathematics experience contribute to determining performance accuracy, inherent traits such as mathematics anxiety may explain the extent to which individuals engage in mathematics-based tasks. Mathematics anxiety is commonly defined as a state of discomfort when faced with mathematics-based tasks (Cemen, 1987; Wood, 1988; Zaslavsky, 1994). However, this definition varies between authors with Cipora et al. (2022) arguing that these subtle differences may actually point towards disparity in the understanding of mathematics anxiety. For example, the authors summarise that definitions vary in strength with some describing mathematics anxiety using relatively mild keywords related to negative *feelings* when faced with situations involving mathematics (F. C. Richardson & Suinn, 1972; Ashcraft, 2002; Ashcraft & Ridley, 2005) whereas others describe mathematics anxiety in the stronger sense of being a clinical *phobia* towards mathematics (Lazurus, 1974; Tobias, 1978; Pizzie & Kraemer, 2017). What is agreed, however, is that mathematics anxiety is linked with mathematics performance and so investigating this relationship further may give insight into the way in which individuals engage with mathematics, particularly with explaining why students may choose not to take post-16 mathematics qualifications.

A natural follow-on question to this would be to ask at what stage of education mathematics anxiety starts to develop. The answer to this is not obvious, despite several decades worth of research investigating mathematics anxiety with a wide range of age groups. For example, some research suggests that the presence of mathematics anxiety in early-age students in Primary Education affects the way that they interact with mathematics such as exhibiting negative associations or task-avoidance behaviours (Krizinger et al., 2009; Hirvonen et al., 2012), however the evidence remains inconsistent here with other studies demonstrating little-to-no effects of mathematics anxiety and associated performance among students in similar age groups (Thomas & Dowker, 2000; Hill et al., 2016). Whilst it is not clear when in Primary Education mathematics anxiety becomes detrimental on mathematics performance, studies have consistently shown that mathematics anxiety is prevalent by the time students are in Secondary Education and remains strong for the remainder of their education career (F. C. Richardson & Suinn, 1972; Hembree, 1990; Hill et al., 2016). This is particularly important for the aims of our study, since studies show that mathematics anxiety remains high in students when starting at university (Rozgonjuk et al., 2020; Daker et al., 2021).

Another important consideration is how mathematics anxiety relates to other types of anxiety such as general anxiety, test anxiety or performance anxiety and whether it is indeed credible as a standalone measure or whether it is merely a dimension of other types of anxiety. For instance, evidence shows that mathematics anxiety correlates positively with other types of anxiety (Hembree, 1990; Ashcraft & Ridley, 2005). Despite this, the large number of studies exhibiting empirical evidence shows that mathematics anxiety cannot be explained be other factors (Dowker et al., 2016). In addition to this, mathematics is unique in that it is a subject that warrants its own type of anxiety, perhaps due to the strong negative feelings associated with learning the subject. Whilst types of anxieties are present in other subjects, such as those with dyslexia learning literacy (Carroll & Iles, 2006) mathematics anxiety has been proven to elicit poorer performance in its related subject which has not been widely evidenced with other subjects such as literacy (Punaro & Reeve, 2012).

Higher mathematics anxiety inhibits the ability for an individual to engage in mathematics which in turn prevents the opportunity to build competency through practice of mathematics-based tasks (Ashcraft, 2002). This may be because mathematics anxiety is negatively related to working memory (Miller et al., 1960; Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974). Various studies have shown that individuals with high levels of mathematics anxiety tend to overload their working memory with thoughts of how badly they are doing which prevents them from engaging their working memory on the skills required to complete mathematics-based tasks (Ashcraft et al., 1998; Hopko et al., 1998; Ashcraft & Kirk, 2001; Pasolunghi et al., 2016; Ching, 2017; Skagerlund et al., 2019). Given that working memory is evidenced to be essential for executing fundamental mathematical manipulation such as arithmetic and algebra, mathematics anxiety may be the link to explaining poor performance in such tasks (Berg, 2008; Raghubar et al., 2010; Cragg et al., 2017).

Whilst some authors state that high levels of mathematics anxiety are widespread in the UK which leads to a general reluctance in studying mathematics (Chinn, 2012), others argue that reasons for choosing to discontinue with post-compulsory mathematics include finding mathematics "hard" or "boring" (Brown et al., 2008; Rigby, 2017). Indeed, these self-beliefs were argued to impact levels of confidence when studying mathematics (McMullan et al., 2012; Sheldrake et al., 2015) which may partly explain why learners struggle and are reluctant to engage with mathematics-based problems in the real-world (Wilson, 2015). Whilst estimates vary as to the prevalence of mathematics anxiety, what is generally agreed is that it is a significant problem (F. C. Richardson & Suinn, 1972; Betz, 1978; Ashcraft & Moore, 2009; Chinn, 2009; Johnston-Wilder et al., 2014).

What also remains unclear is what constitutes *high* and *low* levels of mathematics anxiety. For example, most research focuses on how high levels of mathematics anxiety negatively affects mathematics performance (Ashcraft, 2002). This, in turn, may affect students' decisions to continue with post-compulsory mathematics. However, the inverse implication that individuals with low-to-moderate levels of mathematics anxiety look favourably on mathematics is not widely evidenced. For instance, it might be the case that individuals with low levels of mathematics anxiety still have other negative emotions towards the subject (Larkin & Jorgensen, 2016). As such, it becomes necessary to explore how attitudes towards mathematics relate to levels of mathematics anxiety.

Whilst the wealth of evidence shows that mathematics anxiety is negatively correlated with mathematics performance, there is little empirical evidence to show how to directly alleviate mathematics anxiety. As such, several studies have suggested that focusing on associated factors may, instead, be the way to achieve this. For example, associated confidence, values and self-efficacy have been suggested as important factors to consider (Khasawneh et al., 2021). As such, understanding the relationships between mathematics anxiety and other characteristics are essential for unlocking methods to manage this.

Unfortunately, the evidence suggests that the relationships between mathematics anxiety and associated factors are complex (Devine et al., 2012). Indeed, even the causal direction between mathematics anxiety and mathematics performance is in conflict. For instance, *The Deficit The-*

ory dictates that poor mathematics performance elicits higher levels of mathematics anxiety (Carey et al., 2016). This has been evidenced in studies where children have mathematics-specific learning difficulties such as dyscalculia (Rubinsten & Tannock, 2010; Passolunghi, 2011) as well as longitudinal studies of developing children and adults (Ma & Xu, 2004). On the other hand, *The Debilitating Mathematics Model* suggests that it is high levels of mathematics anxiety which causes poor mathematics performance (Carey et al., 2016). For instance, Hembree (1990) showed that data in their meta-analysis suggested that young adults with high levels of mathematics anxiety are more likely to avoid situations involving mathematics. Furthermore, evidence shows that high levels of mathematics anxiety are linked with low levels of cognitive ability when answering mathematics word problems (Morsany et al., 2014).

Due to strong evidence in support of both directions, Carey et al. (2016) proposed *The Reciprocal Theory* which suggested that both mathematics anxiety and mathematics performance are, in fact, intrinsically linked in a debilitating cycle. More recent evidence has suggested support for this theory (Foley et al., 2017) with Du et al. (2021) showing this bidirectional mathematics performance-anxiety relationship in a longitudinal study with nearly 3000 primary education students in China. However, one must note that students in China will have likely experienced a very different teaching styles and attitudes towards mathematics than those found in the UK (Leung, 2001; Leung & Lopez-Real, 2006; J. Field, 2016). In addition, the participants were Primary Education students and whilst some studies suggest that mathematics anxiety does indeed start at a young age and then tracks individuals for the remainder of their education (Wu et al., 2012; A. Field et al., 2019), it is also suggested that mathematics anxiety and negative associations towards mathematics strengthens as they begin Secondary Education (around 11-years-old) (Dowker et al., 2016). Whilst the findings shown by Du et al. (2021) to corroborate The Reciprocal Theory proposed by Carey et al. (2016) are promising, we must still conclude that empirical evidence which directly supports such a theory remains limited, particular for individuals entering Higher Education.

2.3 The effect of confidence and attitudes and their relationship with mathematics performance

It seems logical to consider that confidence and attitudes towards a subject play an important role in the way in which an individual engages in a task since they will affect one's feelings, thoughts and motivation. This, in turn, will influence how well an individual is likely to perform on that task, since negative associations will likely result in avoidance behaviour and inhibit further learning (Pajares & Miller, 1994). On the other hand, individuals that have a high level of self-confidence and positive attitudes have been evidenced to be more likely to succeed academically, perhaps because these lead to a higher level of resilience when faced with difficulties as part of the learning process (Egorova & Chertkova, 2016; Feldman & Maximilian, 2015; York et al., 2015).

This is especially important in mathematics where A. Smith (2017) highlighted concern of low levels of confidence and negative attitudes towards mathematics which stemmed from earlier reports such as that by Hodgen et al. (2014). Indeed, several studies have highlighted that having positive attitudes and high levels of confidence in mathematics are necessary for an individual to be successful at the subject, especially when compared to individuals who are less confident (Hosein & Harle, 2018; Pajares & Miller, 1994; Honicke & Broadbent, 2016). One needs to be careful, however, of the direction of the effect with some studies showing that high levels of achievement indicate more positive attitudes towards mathematics, however the reverse implication may not be true (Georgiou et al., 2007). It is therefore reasonable to suggest that students' attitudes towards mathematics are led primarily by actually being successful.

There is also some evidence which suggests that the effect of self-reported confidence is closely related to geographic location. For instance, Çiftçi & Yıldız (2019) in their meta-analysis of 336 studies across 76 countries found that whilst confidence levels were positively associated with mathematics performance, this correlation was increased in countries which had higher levels of life expectancy, education and income. Indeed, the authors found that the effect size of self-confidence and mathematics achievement was $d = 0.49$ for England, compared to countries such as Thailand ($d = 0.28$) or Indonesia ($d = 0.10$) suggesting that confidence should give a moderate effect size for individuals from the UK.

It should also be noted that confidence has a strong interaction with subject-specific anxiety, namely mathematics anxiety. In this case, high levels of confidence reduce the likelihood of mathematics anxiety, which in turn is more likely to increase mathematics performance (Feldman & Maximilian, 2015; Kvedere, 2014). It is therefore important to understand that the relationship between confidence, mathematics anxiety and performance is complex and needs to be considered together rather than as separate entities.

Studies have also explored potential reasons why individuals may have differing attitudes or confidence levels towards learning mathematics. For example, Parsons et al. (2009) showed that prior qualifications in mathematics (such as grade achieved at GCSE) had a positive effect on a students' confidence level when engaging in mathematics-based exams at the start of their university degree course, which in turn was associated with higher marks. It has also been suggested that the type of support received from teachers plays an important role as well as the mathematics environment in which the subject is taught (Rawnsley & Fisher, 1998; Schenke et al., 2015), particularly in older students (Evans & Field, 2020).

2.4 Personality and its relationship with mathematics performance

The Big Five, sometimes referred to as the Five-Factor Model (FFM), models personality according to five broad dimensions (John, 1990; McCrae & John, 1992; John & Srivastava, 1999; John et al., 2008):

Openness – intellectual, polished, independent-minded.

Conscientiousness – orderly, responsible, dependable.

Extraversion – talkative, assertive, energetic.

Agreeableness – good-natured, cooperative, trustful.

Neuroticism – anxious, depressed, irritable.

In this research we aimed to show how certain personality traits are beneficial for academic performance, specifically in relation to mathematics performance. There exists a large number of studies which have investigated the link between individual personality traits and academic performance from several decades (De Raad & Schouwenburg, 1996; Chamorro-Premuzic & Furnham, 2003; Conard, 2006; Laidra et al., 2006; Poropat, 2014; Noftle & Robins, 2007) and this has also been the subject of several meta-analyses (O'Connor & Paunonen, 2007; Poropat, 2009; Mammadov, 2022). However, there are fewer studies which have explored the effect in which these personality traits relate to performance accuracy on domain-specific tasks such as mathematics. As such, we describe the current evidence that shows relationships between each personality trait and academic performance and highlight, where possible, work which has looked specifically at this with regards to performance accuracy on mathematics-based tasks.

Whilst cognitive ability (such as critical thinking skills) remains a strong predictor of academic achievement, it has been suggested that this tends to shift over one's educational development towards domain-specific knowledge which, in turn, are reflected by levels of personality traits (Ackerman et al., 2001). Indeed, Furnham & Chamorro-Premuzic (2004) argued that whilst cognitive ability may well determine the potential academic capabilities of an individual, it is personality traits which determine whether an individual will actually engage with the relevant activities required to fulfil that academic potential. This is more likely to be true among university students where the decision to engage with learning tasks in a highly domain-specific subject area firmly lies with the student, as opposed to the encouragement from external influences such as a teacher or parent. Personality traits have also been shown to stabilise by the time students start at university (Soto et al., 2010) and it has been suggested that they are a stronger predictor of academic performance than cognitive ability among such students (O'Connor & Paunonen, 2007).

Evidence shows that conscientiousness is a reliable and positive predictor of academic performance (Conard, 2006; Hazrati-Viari et al., 2012; Vitulić & Zupančič, 2013; Mitrofana & Iona, 2013; Chamorro-Premuzic & Furnham, 2003; Higgins et al., 2007). Given that the conscientiousness trait describes individuals who are self-disciplined, achievement-orientated and ordered (McCrae & John, 1992), one can see why this would elicit better academic performance since these are generally accepted traits that are necessary for effective preparation in academic assessments. In addition, some studies have expanded on this to find that conscientiousness is positively associated with specific types of motivation and an ability to consolidate learning (Anderson & Keith, 1997; Colquitt & Simmering, 1998; M. Richardson & Abraham, 2009; Drabick et al., 2007).

Whilst conscientiousness tends to be a trait positively correlated with academic performance, the neuroticism trait tends to elicit negative associations (Chamorro-Premuzic & Furnham, 2003; Laidra et al., 2006; Deschler & Fuller, n.d.; Gerbino et al., 2018). Given that neuroticism tends to describe individuals who are self-conscious and anxious (McCrae & John, 1992), it is perhaps unsurprising that such individuals would also experience heightened levels of test anxiety (O'Connor & Paunonen, 2007; Chamorro-Premuzic et al., 2008) and perceive themselves as under-performing which in turn can affect working memory as described in Section 2.2.

The associations between academic performance and other personality traits remain generally mixed. For example, some studies have found positive correlations between openness and academic performance (Duff et al., 2004; Laidra et al., 2006; Komarraju et al., 2009; Smidt, 2015), perhaps due to the trait lending itself to individuals with intellectual values and ideas (McCrae & John, 1992). Indeed, some authors have argued that individuals with high levels of openness tend to be more curious in learning new things which should be positive for encountering new learning opportunities (Ziegler et al., 2012), and De Raad & Schouwenburg (1996) stated that openness *"contains traits that seem to form a cluster of the ideal student"* (p. 237). However, most meta-analyses have only reported weak to moderate correlations between openness and academic performance (Poropat, 2009; M. Richardson et al., 2012; Mammadov, 2022).

The relationship between academic performance and extraversion and agreeableness becomes weaker still with conflicting evidence about both the strength and direction of the associations in these personality traits. For example, some studies have found evidence that extraverts exhibit higher performance accuracy (Thiele et al., 2018), whilst other studies have reported either null findings (Ciorbea & Pasarica, 2013) or reversed patterns (Furnham et al., 2013). Evidence also remains similarly mixed for agreeableness (Brandt et al. 2020 [negative]; Poropat 2009 [weak, but positive]; M. Richardson et al. 2012 [positive]). A plausible argument is that both extraversion and agreeableness relate to how individuals interact with each other and so it is important to consider the method in which academic performance is measured. For example, if an assessment relies on being able to share and listen to ideas in which work is produced collaboratively as a group, then such traits could elicit positive performance associations. This has been evidenced in studies where participants have been given non-academic group tasks (LePine & Van Dyne, 2001; Kramer et al., 2014).

Of particular note is to understand how these correlations vary across different age ranges of students. A recent meta-analysis conducted by Mammadov (2022) which synthesised results from over 413,074 individuals in over 200 studies was able to determine differences between the strengths of correlations between personality traits and academic performance for students in early years education, secondary education and university level education (which the author termed “post-secondary”). They found that openness-academic performance correlations were strongly positive for early years students ($\rho = 0.40$) and weaker for students in university education ($\rho = 0.10$). Similarly, extraversion was positively correlated for students in early years education ($\rho = 0.15$), however this dropped to $\rho = 0.01$ and $\rho = -0.01$ for students in secondary education and university education, respectively, and agreeableness experienced a similar negative decline across the age ranges (early years: $\rho = 0.18$; secondary: $\rho = 0.08$; university: $\rho = 0.08$). Conscientiousness remained a positive and consistent correlation of academic performance across the age ranges ($\rho = 0.31, 0.27, 0.26$ for early years, secondary, university students, respectively). However, neuroticism remained as a very weak negative predictor of academic performance ($\rho = -0.01, -0.01, -0.02$ for early years, secondary, university students, respectively). These findings follow on from a meta-analysis using over 50,000 individuals conducted by Poropat (2009), which found similar patterns in the correlations for each personality trait across the age ranges, although their correlations were slightly weaker overall than Mammadov (2022). As such, for university students in particular it should be expected that conscientiousness should remain as a strong predictor of academic performance, whilst other personality traits may elicit marginal associations.

Whilst there may be a shortage of evidence on the correlations between individual personality traits and mathematics-specific performance, this does not mean that this field is completely unexplored. Indeed, Alcock et al. (2014) found that personality traits were a better predictor of a university student's mathematics performance than gender. Of the Big Five personality traits, openness has been shown to have consistent positive correlations for success in mathematics-specific tasks (Moses et al., 2011), however, similar to the effects of this trait on general academic performance, other studies have contradicted this with no significant correlations found (Meyer et al., 2019), or even correlations in the negative direction (Lipnevich et al., 2016). Similarly, the association between other personality traits and mathematics performance have reported widely mixed results (Lipnevich et al., 2016; Meyer et al., 2019; Opstad, 2021), however one could argue that this mixed evidence is to be expected given that the same fluctuations sometimes occur with studies exploring the effects of personality traits on performance in general academic tasks. Indeed, more evidence is required in order to make substantive conclusions in the direction of associations between personality traits and mathematics performance.

3 Mathematics Pathways in the UK

Chapter 3 Contents

This chapter will summarise post-16 mathematics pathways in the UK and how this research aimed to address some of the unanswered questions surrounding its shortages. We will do this by first considering the key reforms to the education system within the UK between 1950 and the present day. Whilst it can be argued that some noticeable historical legislation occurred before 1950 which contributed to the evolution of the education system, this chapter is intended to give the reader context and understanding of the major education reforms that have directly led to the shape of the current education landscape. Once the present education system has been summarised, this chapter will help to provide a snapshot of the recent changes to UK education that have given motivation for undertaking this research as described in Section 1.2. In particular, the main findings of the Smith Review (A. Smith, 2017) will be discussed in Section 3.6 as well as the post-16 mathematics pathways that are available to learners in Section 3.3. This chapter will also explore the effects of these post-16 mathematics pathways for students transitioning to university in Section 3.5 and the implications for our research in Section 3.7.

3.1 Major Reforms to the Education System: 1950-Present Day

The aim of this subsection is to outline key reforms to the education system which affects the way that post-16 mathematics was historically and is presently made available to learners in full-time education. The rationale of this is because this research was conducted in the wake of major reforms to the education system in 2015. As such, it is deemed necessary to have a broad overview of previous education reforms in order to set this research properly in context. We also provide an overview of some of the reforms to Secondary Education since this has implications for the opportunities for post-16 study.

3.1.1 Education Reforms: 1950-2000

One of the key reforms pertinent to this discussion was the introduction of the General Certificate of Education (GCE) qualifications in 1951. Whilst these were originally split into Ordinary Levels (O-Levels) for 16-year-olds and Advanced Levels (A-Levels) for 18-year-olds, they were only accessible to the top 20% of learners determined by ability. This meant that around 80% of students were leaving school unqualified and so, in 1965, the Secondary School Examination Council (SSEC) introduced the Certificate in Secondary Education (CSE) for the next 20% of 16-year-olds (determined by ability) not taking O-Levels (Gillard, 2018). This was then followed by Curriculum 11-16 (Department of Education and Science, 1978) in 1978 which implemented a common curriculum that teachers had to follow. Subsequently, as part of the Education Reform Act 1988 (DfE, 1988), the National Curriculum was introduced which was intended as a common means of testing and assessing the abilities of students through a common curriculum that would be taught to all students.

Two major qualifications were also introduced at this time: the General Certificate of Secondary Education (GCSE) and the Advanced Supplementary Level (AS-Level). GCSEs replaced the existing qualifications for students aged 11-16 and were intended to be taken by all learners when leaving Secondary Education at the age of 16. The aim of GCSEs was to cater for a wider ability range and allowed lower-achieving students to work towards qualifications (DfE, 1985). GCSEs were designed to complement the National Curriculum by encouraging students to study three core subjects (mathematics, English and science) and seven foundation subjects (history, geography, technology, music, art, physical education and a modern foreign language). This meant that more students were leaving school with qualifications that were previously inaccessible to them, implying that they had a greater range of skill and knowledge than they did previously (Oates, 2021).

GCSEs also meant that more students could continue with Further Education between the ages of 16–18 since they were better-qualified to do so (Bolton, 2012). To complement this, the introduction of the AS-Level was designed to sit as an intermediary qualification between GCSEs and the existing A-Levels. It was advertised as the equivalent to half of an A-Level and provided greater opportunity for students to obtain a post-16 qualification after completing their GCSEs (Baker, 1988). Despite this, its success was doubted and so Dearing (1996) recommended changes such as a greater focus on skills and more consistency of standards at A-Level which resulted in a reformulation of AS-Levels, leading to a major education reform termed *Curriculum 2000*.

3.1.2 Education Reforms: 2000-2015

The Reform of A-Levels

Introduced in September 2000, Curriculum 2000 revised the way in which A-Levels were taught and structured (House of Commons Education and Skills Committee, 2003b). These changes prescribed that A-Levels would be taught and assessed according to a modular structure as opposed to the variety of linear and modular structures that existed prior to this reform. In the case of A-Level Mathematics, students would take six modules across the course with three modules studied per year. AS-Levels - which were previously a separate standalone qualification - were also merged to become part of the A-Level qualification such that the first three modules examined in Year 12 would qualify for an AS-Level. A student could then decide to continue on to the second year of the course and sit the next three modules which would qualify for an A2-Level. The AS- and A2-Level grades would then combine with equal weighting to make the full A-Level qualification. The fact that an AS-Level stood as a standalone qualification gave students the increased flexibility to only sit the first year of an A-Level course whilst still achieving an accredited qualification. It was intended that this restructuring would give students a broader range of study during Year 12 with the option to study four or five subjects (as opposed to the traditional three) and then narrow down their studies by opting to discontinue with one of their subjects prior to starting Year 13 (House of Commons Education and Skills Committee, 2003a).

Whilst early concerns were exhibited as to whether the A-Level course had lowered its standards (Priestley, 2003), Tomlinson (2002) concluded that as a result of the restructuring of A-Levels in favour of a modular system, more students had access to an A-Level without any increase to the overall level of demand of the qualification. The author also highlighted that students would have access to a broader range of subjects taken within the A-Level course. This was corroborated by the Office for Standards in Education, Children's Services and Skills (Ofsted) which noted that it was typical for students to take four or five subjects at AS-Level and then drop one of these in the second year of the A-Level course (Ofsted, 2003).

Effect of Curriculum 2000 on A-Level Mathematics and Further Mathematics

Despite positive sentiments about Curriculum 2000, A-Level Mathematics entries fell by 24% from 71 000 in 1998 to just 54 000 in 2002 with a similar substantial drop in students taking Further Mathematics in the wake of its introduction (Matthews & Pepper, 2006). This trend was confirmed in the 2004 Smith Report (A. Smith, 2004) which highlighted concern in three major areas: the first being that the resulting curriculum and qualification framework imposed by Curriculum 2000 failed to meet the requirements of learners and the needs and expectations of Higher Education and employers to encourage students to continue into post-16 mathematics; the second highlighted the shortage of mathematics-specialist teachers who could teach the qualification to the required standard; the third addressed the lack of support infrastructure such as professional development and resources.

In response to this drop in numbers, in 2004 A-Level Mathematics underwent restructuring with the intention to motivate increased awareness of the subject's importance for Higher Education and employment and to create more emphasis on understanding and applications (Ofqual, 2009). A revised syllabus was put in place that restructured the six modules to incorporate a greater amount of pure mathematics and less content on applied mathematics as well as reworking early modules to allow students to have a better transition from GCSE into A-Level content (QCA, 2006). There were also additional support networks put in place through government investment as well as the Further Mathematics Network and the Further Mathematics Support Programme that aimed to support students and teachers (Lee et al., 2016). After these changes, candidates taking A-Level Mathematics successfully increased from 52 897 in 2005 to 95 244 in 2017 and similarly for A-Level Further Mathematics from 5933 in 2005 to 16 172 in 2017 (JCQ, 2023).

3.1.3 Education Reforms: 2015-Present

In 2015, another major reform was introduced by the previous Secretary of State for Education, Michael Gove, that would affect both GCSEs and A-Levels as well as making it compulsory for students to remain in education or employment training until the age of 18 in England (DfE, 2013; DfE, 2013). Both GCSE and A-Level qualifications moved away from the modular system of assessment introduced in Curriculum 2000 and reverted to assessments taken at the end of the course as seen prior to 2000. With regards to GCSEs, the grading system was changed from the previously-used lettered grading system introduced in 1963 to a numerical grading system ranging from a grade 9 as the top grade through to a grade 1 as the lowest awarded grade with grades 4-9 seen as a pass. The intention of using this numerical grading system was to allow for more distinction between the middle grades (Ofqual, 2018). In addition, the introduction of a new top grade (grade 9) would only be awarded to the top 3% of candidates and thus aimed to help Further and Higher Education establishments recognise the highest achieving students (Ofqual, 2017). In addition, new content was added to GCSE Mathematics with an increased emphasis on problem-solving questions as well as questions designed to assess content from across the syllabus simultaneously. Content was also introduced that would previously have been seen in A-Level Mathematics such as numerical methods and functions and there was a significant increase in content which used ratio and proportion (Ofqual, 2019).

To complement these changes to the GCSEs, in 2010 the Department for Education introduced the English Baccalaureate (EBacc) scheme (House of Commons Education and Skills Committee, 2011). Initially intended to promote subjects essential for university, the EBacc was a list of preferred core subjects (English [Language and Literature], Mathematics, Sciences, Modern or Ancient Foreign Language, Geography or History) which the government believed are essential for building a broad range of knowledge. The EBacc did not provide students with any additional qualifications to their GCSEs, instead it was intended as a performance measure for schools to ensure that they are targeting attention towards their students passing these core subjects listed. The government argued that it promoted the study of fundamental subjects at GCSE, ensuring that teaching and learning is targeted towards subjects which students will rely on in future life (DfE, 2010). They also argued that the EBacc promoted the study of these subjects for disadvantaged pupils, however this was disputed (The Sutton Trust, 2018). Indeed, entries to EBacc subjects increased in the decade since it was introduced (see, for example, JCQ data (JCQ, 2023)). However, Richmond (2019) stated that the EBacc was damaging towards other subjects which were not listed but are essential for promoting creativity and cultural awareness. Indeed, the author stated that several of the subjects which are not listed in the EBacc such as art and drama have seen a drop in GCSE entries in the last decade since the EBacc was introduced. Greevy et al. (2012) argued that this was because schools have changed the way in which they deliver the creative arts subjects, sometimes redistributing staff as a result of the EBacc. The authors also found that mixed messaging was being provided to students about the aims and importance of the EBacc which was compounded by the shortage of teachers for EBacc subjects, particularly in mathematics. For example, the government advertised the EBacc as a set of important subjects which would help students when applying for university (DfE, 2018). However, since the introduction of the EBacc in 2010, Russell Group universities have withdrawn their emphasis of these facilitating GCSE subjects for university entry which has resulted in a lack of clarity of the current purpose of the EBacc (Bloom, 2019). Despite this, the introduction of the EBacc reinforces the government's belief that mathematics should form an integral part of a child's education, even before 16-18 Further Education study.

Whilst A-Level Mathematics and Further Mathematics were reformed in 2017 and only had relatively minor changes to the syllabus, they were affected by the restructuring in the 2015 reforms which saw the decoupling of AS-Levels and A-Levels, effectively reverting to the system as seen pre-Curriculum 2000 (Glaister, 2017a). Whilst AS-Levels remained an available qualification, students and Further Education colleges clearly viewed them as being less valuable with a substantial drop in the number of students taking AS-Levels in Mathematics from 160 450 in 2017 (the last cohort of students prior to the decoupling of AS- and A-Levels) to 81 051 in 2018 with a decreasing trend in recent years to just 16 844 in 2022 (JCQ, 2023).

The changes also prescribed that it was compulsory for all students to study a statistics and mechanics component in A-Level Mathematics, thus removing the flexibility of applied mathematics options given prior to the 2015 reforms. This change did make it easier for universities to be more certain about the types of mathematics knowledge which a student with A-Level Mathematics had. Due to recommendations from the Royal Statistical Society and the A-Level Content Advisory Board (ALCAB, 2014), there was also the introduction of a Large Data Set (LDS) as part of the initiative to encourage statistical interpretation of data. This gave students the opportunity to investigate a real-life data set using the statistical skills that they had learnt during the course and was assessed as part of the examination in AS- and A-Level Mathematics. Whilst there was still the option to take a module in Decision Mathematics, this was only made available to students taking A-Level Further Mathematics. The changes were under the review and guidance of ALCAB which outlined that the new A-Level Mathematics should build on content taught at GCSE whilst emphasising how mathematics ideas are interconnected. The A-Level was designed to put more emphasis on mathematical problem solving using real-life scenarios to enable students to show more of an understanding of the physical world. The course was also redesigned to put a stronger emphasis on proof and mathematical language whilst removing scaffolding from assessment questions which was a criticism of the previous system (Glaister, 2017a). The A-Level was designed with Higher Education and employers in mind and it was intended that this reform would allow content to change in response to technological development and changes within mathematics itself. This was one of the biggest aims of the introduction of the LDS which was seen as a tool to inform the teaching of the statistics element of the A-Level in Mathematics (DfE, 2016).

3.1.4 Education Reforms 1950-Present: A Discussion

There have been numerous education reforms in the decades since 1950, each of which have contributed to the shape of the current education landscape. Whilst each reform has had slightly different intended aims, the underlying theme has been to make education more available and accessible to a greater number of learners. Some criticise that this can result in a "dumbing down" of qualifications (House of Commons Education and Skills Committee, 2005), however others argue that increasing their accessibility has its advantages: namely, so that the UK has a more skilled and qualified workforce which is of benefit to the economy (A. Smith, 2017).

The introduction of the National Curriculum and GCSEs in the late 1980s has meant there are currently around 600 000 15- and 16-year-olds taking GCSEs each year (JCQ, 2023), with the aim that every student achieves a pass grade in the core subjects of English and mathematics (UK Government, 2014). In 2010, this was reemphasised with the introduction of the EBacc framework at GCSE which was used as a metric of school performance by ensuring that core subjects, including mathematics, were taught well. Whilst our research did not focus specifically on GCSE level study, it is important to note that a student's decision to enrol on post-16 mathematics study is often decided at this level (i.e., before starting in Further Education). As such, the reader should be aware of the broad initiatives of GCSE Mathematics as they may hold some influence over whether a student decides to continue with post-compulsory mathematics study.

Recent reforms have made it compulsory for all learners in England to remain in some form of education or employment training until the age of 18, which results in around 500 000 of these students remaining in full-time education each year - around 300 000 of which are studying A-Levels and 90 000 are studying A-Level Mathematics (JCQ, 2023). Despite this, there is still a significant skills shortage of mathematics and numeracy skills with negative associations towards mathematics remaining prevalent in UK society (National Numeracy, 2019). Whilst it is compulsory to pass GCSE Mathematics at the age of 16, a large number of students choose

Table 3.1 | A timeline of the major education reforms and their associated implications for the way that subjects were taught and assessed for learners aged 5 to 18 between 1947 to the present day.

Year	Reform	Description
1947	Increased school leaving age	Compulsory to remain in education until the age of 15.
1951	GCEs introduced	Two levels of qualifications: • O-Levels (for top 20% of 11- to 16-year-olds). • A-Levels (for 16- to 18-year-olds).
1965	CSEs introduced	Available for the next 40% of most able 11- to 16-year-olds not sitting O-Levels.
1973	Increased school leaving age	Compulsory to remain in education until the age of 16.
1978	Curriculum 11-16	Imposed a common curriculum taught in schools.
1988	National Curriculum	Standardised the content taught to 5- to 16-year-olds and how it was assessed. The curriculum consisted of core subjects (including mathematics) and foundation subjects.
1988	GCSEs introduced	Replaced O-Levels and CSEs so that *all* 11- to 16-year-olds would study and receive a secondary qualification.
1989	AS-Levels introduced	Equivalent to half an A-Level that was designed as a post-16 intermediary qualification between GCSEs and A-Levels.
2000	Curriculum 2000	Major restructuring of A-Level courses: • AS-Level qualifications would combine with A2-Level qualifications to form a complete A-Level. • Move to a modular approach to AS- and A-Level assessments where assessments were taken throughout the two-year course of study.
2015	Gove's Reforms	Restructuring of A-Levels and GCSEs: • Decoupling of AS- and A-Levels. • Introduction of LDS in A-Level Mathematics. • A proportion of mathematics skills content should permeate certain subjects. • Harder content introduced in GCSEs. • Assessments taken at the end of the course.

not to study post-16 mathematics (Homer et al., 2020). This has been picked up by prominent figures in the UK and so in the next section we aim to provide an overview of the important statements from the government.

3.2 Post-16 Mathematics in UK Parliament

In the last decade, various prominent figures in the UK parliament have endorsed ambitions to make mathematics compulsory after the age of 16. For instance, in 2011, then education secretary Michael Gove made a speech to the Royal Society which set out the ambition that within a decade the majority of learners in 16-18 education would be studying mathematics (DfE, 2011). In 2015, the Labour party published its manifesto with similar aims (Page 37, The Labour Party 2015), and in 2017 the government-commissioned Smith Review (A. Smith, 2017) recommended for mathematics to be made available to all learners after the age of 16. Over a decade has now passed since Michael Gove's original speech and yet, in 2023, the Prime Minister renewed these discussions, showing that this remains a current topic that is still of interest and importance.

In 2023, the Prime Minister (PM) Rishi Sunak announced various proposals which centred on the mathematics skills shortages in the economy and workplace. These proposals emphasised the need for a more numerate society reflecting statements such as that by National Numeracy (2019) which said that 49% of UK adults had the same level of numeracy as an 11-year-old with 30% of 18-24 year olds stating that using mathematics made them feel anxious. This points towards criticism of how well the mathematics taught in schools actually prepares students for future life. Indeed, Harding et al. (2012) found that only 22% of UK adults retained the required numeracy levels to pass GCSE Mathematics, despite GCSE Mathematics being seen as one of the expected qualifications which all 16-year-olds are expected to leave school with (UK Government, 2023). This clear shortage of mathematics skills amounts to an estimated yearly cost to the UK economy of £20 billion (National Numeracy, 2019), so naturally this is a high priority for the UK Government to address.

In January 2023, the PM announced plans to make some form of post-16 mathematics compulsory until the age of 18 (UK Government, 2023e). This was very much in line with the previous sentiments of government ministers (e.g., DfE, 2011) as well as the Smith Review (A. Smith, 2017) where guidance was given to make mathematics available, but not necessarily compulsory, to learners up until the age of 18. This plan was, however, greeted with criticism with many citing shortages in the workforce of qualified mathematics teachers and the urgency to stem the teacher retention crisis (The Nuffield Foundation, 2023b). There was also confusion over what type of mathematics would be taught between the ages of 16-18, with the PM later clarifying that this would not exclusively be A-Level Mathematics (UK Government, 2023d). Supporters did, however, urge the case of Core Mathematics as being a viable option, using this statement from the PM as an opportunity to make further encouragement in this direction (AMSP, 2023).

In April 2023, the PM furthered his January statement by announcing a review of the mathematics content taught in school with the aim of tackling the “anti-mathematics mindset” (UK Government, 2023d). Similar to the announcement in January 2023, the PM emphasised the negative effect of these mathematics skills shortages on the economy and workplace. He urged for a review into the types of mathematics taught in schools such as ways to make the mathematics more relevant and strengthening the mathematics taught at an early age. The PM argued that this was still part of the aim to make mathematics in the UK compulsory until the age of 18, and that they would also review what types of mathematics content other countries are studying between ages 16-18 as well as the mathematics needs of employers.

Several education organisations and notable experts responded to these plans. For instance, National Numeracy 2023 highlighted that the issue of poor numeracy skills stems from societal attitudes and that more work needs to be focused on adults and children alike in order to build confidence and perceived value in mathematics. They argued that there was a distinction to be made between everyday mathematics and classroom mathematics: the former being a potential solution to changing societal attitudes by building confidence and value in mathematics through its relatable uses; the latter being a cause of anxiety and avoidance of adult mathematics, particularly the high failure rate (a third) in GCSE Mathematics.

Others argued that a low-stakes form of testing mathematics may be required, with an emphasis on linking this to existing subjects (Norris, 2023). In fact, as part of the 2015 education system reforms, there were specified minimum required levels of mathematics content for certain subjects in order to emphasise the importance and relevance of these skills (Norris & Noyes, 2023).

Some individuals maintained the argument that Core Mathematics is a viable existing solution that is still somewhat failing to get recognition in these discussions and proposals from the PM (Hillman, 2023). For example, one of the main aims of Core Mathematics was to target the large numbers of students who have reached a Level 4 pass grade in GCSE Mathematics, and thus limit the attrition of these skills in the time between age 16 and starting university or work in the so-called "mathematics gap" (DfE, 2013). Core Mathematics also complements some of the sentiments of National Numeracy (2023), by using real-world mathematical applications as a framework to teach concepts. It should also be noted that this issue of negative attitudes towards continuing with post-16 mathematics has lasted for over 15 years. For example, Brown et al. (2008) published findings of their survey of 1997 GCSE candidates as to whether they are likely to continue studying mathematics after it ceases to become compulsory. Many participants stated that their reasons for not doing so were due to their lack of confidence, being highly anxious, perceived high difficulty of the subject and the lack of relevance in the content taught.

The general conclusion that can be drawn from the published responses to the PM's statements is that, whilst the mathematics shortage clearly exists in the UK, the problem is multi-faceted. There is a recognised need to address the confidence and anxiety issues facing learners of mathematics as well as the perception that the mathematics content taught in the classroom is hard or has little relevance to everyday life (Brown et al., 2008; Sealey & Noyes, 2010; Hodgen et al., 2017), however there is little consensus over how to achieve this and which age group needs to be targeted in order to have the most impact on combating these negative associations. Some responses (e.g., Hillman, 2023) call for more recognition of the existing mathematics options offered post-16, with Core Mathematics being at the forefront of these discussions; others (e.g., Barton, 2003) recognise a need to target GCSE Mathematics and its suitability at preparing students for the mathematics of the workplace; whilst National Numeracy (2023) are among those emphasising the importance of working with adults and primary school children to change negative societal perceptions of mathematics.

The aim of this research was to provide evidence of the shortage of mathematics skills from the perspective of Higher Education. Indeed, only a few studies have looked in this direction (e.g., Thompson et al., 2015; Darlington & Bowyer, 2017; Adkins & Noyes, 2018) and fewer still have responded in the wake of the 2015 education reforms or to the Smith Review (A. Smith, 2017).

3.3 Mathematics Pathways in the UK

As outlined in section Section 1.1, the aim of the UK government is that all students should leave Secondary Education having passed GCSE Mathematics. It is then compulsory to continue in education in England until the age of 18, however a post-16 mathematics option is not currently compulsory for those who have passed GCSE Mathematics. This gives rise to the so-called "mathematics gap" (DfE, 2013). In this section, we aim to outline all current and some former post-16 mathematics pathways which are available to learners and provide evidence of their advantages and disadvantages.

3.3.1 Broad Post-16 Pathways in the UK

There are several types of post-16 pathways offered to learners between the ages of 16-18. Generally these are divided into either:

Vocational pathways – e.g., Business and Technology Education Council (BTEC), traineeship, advanced apprenticeship.

Technical pathways – e.g., Technical Levels (T-Levels).

Academic pathways – e.g., Advanced Levels (A-Levels), International Baccalaureate (IB).

Whilst not a main focus of our research, T-Levels are a new Level 3 qualification introduced in September 2020 as an equivalent in UCAS points to three A-Levels and focuses on one particular specialist skill area for the duration of the two-year course (DfE, 2023). However, T-Levels still have a traditional examination form of assessment which is similar to the structure seen in A-Levels. The popularity of BTECs was on par with A-Levels, with approximately 200 000 students each year choosing this qualification, however the government plans to reduce the BTEC provisions in favour of T-Levels from 2024 (Lewis, 2021). Despite a T-Level course being intended as equivalent to a course with three A-Levels, concerns have been raised over whether universities have the same view. For example, in the 2022-23 academic year, less than half of traditional UK universities accepted students with T-Levels on at least one of their courses, of which only 14 were in the elite group of 24 Russell Group universities (Education and Skills Funding Agency, 2021). In addition, the statements provided by some universities regarding T-Levels can be confusing for certain subjects. For example, the University of West England (UWE, 2024) state that their BSc(Hons) degree course in Mathematics will accept T-Levels providing that an applicant also has an A-Level in Mathematics:

> *"**T Levels:** Grade B in A-Level Mathematics, in addition to your T Level qualification. If you have or are looking to partially complete your T-Level, you are still required to have the equivalent to 2 full A-Levels as part of our minimum entry requirements. As a result, if you are applying with only the core or occupational specialism, this may be insufficient as a standalone qualification."*

However, mathematics plays an compulsory part of a T-Level course, with the relevant quantitative skills being integrated and assessed as part of the course.

Despite this, the mathematics which is utilised on technical and vocational pathways is usually equivalent to a Level 2 education standard and so for this reason, we will focus this research on academic pathways where it more likely that students will have access to a Level 3 qualification in mathematics. In addition, this research is aimed at learners transitioning into university Higher Education, and so it is more likely that these learners will have undertaken full-time post-16 education courses, although we accept that a small number of university courses may accept learners who have studied certain technical pathways (DfE, 2023).

A-Levels are one of the most popular academic pathway with approximately 300 000 students choosing this route each year (UK Government, 2022). This accounted for almost half of all learners taking this option in 2017 (page 16, Department for Education (DfE), 2019). Between 2000 and 2014, all UK students were required to take an AS-Level qualification in the first year of their two-year A-Level course which would have constituted approximately 40% of a full A-Level in each respective subject. This AS-Level would have then been combined with the second-year part of the course (termed *A2*) in order to make the full A-Level qualification. Whilst this process still continues in Wales and Northern Ireland, AS- and A-Levels have been decoupled in England since 2015 (Ofqual, 2018). Students embarking on an A-Level course will typically choose three subjects to study. However, the choice of which combinations of subjects can matter for students hoping to transition to university study. For example, the University of Cambridge suggested that students who are less sure about what degree course they would like to take, might opt for combinations of arts and science A-Levels; however, this may make them a less competitive candidate for degree courses in the sciences. Indeed, they even imply that a criteria to gain a place on their competitive science degree courses requires applicants to have chosen all of their A-Levels in mathematics and sciences (University of Cambridge, 2022). This work has also been furthered by (Lee et al., 2017) who have shown that universities can have strong requirements of specific post-16 subjects in STEM and STEM-related degree courses. This is perhaps unsurprising given that a sufficient depth of knowledge will be expected in certain areas prior to starting on such degree courses which can only be obtained by studying these A-Levels. Indeed, the Russell Group formerly offered a list of Facilitating Subjects and has since been replaced by its Informed Choices service which guides students through the process of choosing post-16 options based on their preferred degree subject (Russell Group, 2019).

The IB (Diploma) is a two-year course which is regarded as an alternative to traditional A-Levels (University and Colleges Admissions Service (UCAS), 2023). Similar to the EBacc, students will study subjects from five areas (two languages [e.g., a first/native language and a modern foreign language], a social science, an experimental science, and mathematics), ensuring that a breadth of knowledge is covered. Students will then have the choice of studying a sixth subject from an arts area or an additional subject from the five existing areas. The IB allows for a level of flexibility in the choice of the six subjects chosen, whilst still prescribing that a wide range of subject areas must be studied, including mathematics. In contrast, A-Levels encourage focused study in any three subject areas, which may not appeal to students with a wide range of academic abilities and interests in the same way that the IB does. Some form of post-16 mathematics is already compulsory on the IB, with the option of studying more mathematics through the use of the sixth subject if students are looking to continue mathematics further in a career or Higher Education. Whilst this is clearly positive for the case for post-16 mathematics in that all students on the IB will be taking a compulsory mathematics subject, the uptake of the IB is generally small in the UK with around 5 000 learners taking the qualification each year (Organisation, 2023). This is partly because there are only a small number of Further Education colleges which offer the IB as a post-16 education pathway in the UK. This is surprising since the IB, as the name suggests, is an internationally recognised qualification which makes it easier for students to study at universities in several other countries, as well as offering a wide range of subjects similar to the style of GCSEs in the UK. In addition, the wider range of subjects studied in the IB means that students can sometimes be less limited by their chosen post-16 subjects when applying for their university courses, unlike in A-Levels. However, one potential reason for the low levels of uptake of the IB is that it requires more work than A-Levels due to six subjects studied instead of the traditional three at A-Level as well as independent work in the form of a research essay and 150 hours of extracurricular activities (Organisation, 2024). Also, most UK universities do not especially favour the IB over A-Levels with typical entry offers specified on the award of three A-Level grades or the equivalent in UCAS points Table 3.4. Since the IB clearly involves a higher level of workload than the typical A-Level course structure, this may lead students to wonder why they should invest additional time and workload for the same level of recognition from universities as their A-Level counterparts.

The common theme among full-time post-16 education pathway provisions is that universities drive their success since many students consider degree schemes when choosing which post-16 options to take (Lee et al., 2017; Russell Group, 2019; University of Cambridge, 2022). Offers from universities typically consist of A-Level grades and equivalent UCAS points, with the latter being used to account for the other range of post-16 pathways available to learners in 16-18 education. However, A-Levels are the only one of these post-16 pathways which are universally and explicitly mentioned in university admissions, despite a comparatively high number of students also taking BTECs and potentially the new T-Levels when they take over from BTECs in 2024. Combining this with the fact that less than half of traditional UK universities currently accept T-Levels suggests that there is a clear preference for applicants with A-Levels. This is problematic for post-16 mathematics, as other post-16 pathways such as T-Levels and the IB have compulsory mathematics elements integrated within them, whereas A-Levels currently do not. As such, this research sets out to provide evidence of the value of post-16 mathematics qualifications and so the messaging which universities give towards alternative post-16 education pathways may need to be reconsidered in the future. In the next subsections we will outline the post-16 mathematics options specific to learners in full-time education and review the evidence regarding advantages and disadvantages to each.

3.3.2 GCSE Mathematics Exam Retakes

Since 2014, the UK government has made it compulsory for most students in Further Education who do not achieve a Level 4-9 in their GCSE Mathematics to retake the examination alongside studying their other post-16 subjects until they achieve one of these pass grades (Education and Skills Funding Agency, 2014a). This is reflective of the aim that all students will leave formal education having achieved a Level 2 qualification in mathematics. However, this policy has been met with criticism, with some questioning whether it is actually beneficial to replicate the same types of mathematics repeatedly until students achieve a pass when alternative mathematics could be studied instead (The Nuffield Foundation, 2020). Individuals have proposed alternatives such as the option for students to study types of mathematics that are directly useful to their post-16 course (Dalby & Noyes, 2016). Indeed, some responses to the PM's statements regarding post-16 mathematics question whether GCSE Mathematics is fit for purpose (National Numeracy, 2023).

3.3.3 A-Level Mathematics

The most popular A-Level in the UK is Mathematics with around 90 000 students taking the subject each year (Figure 3.1, JCQ, 2023). Since Curriculum 2000, A-Level Mathematics has remained as one of the five most-popular A-Levels Figure 3.2, however there are barriers which prevent more students taking this as a post-16 mathematics subject.

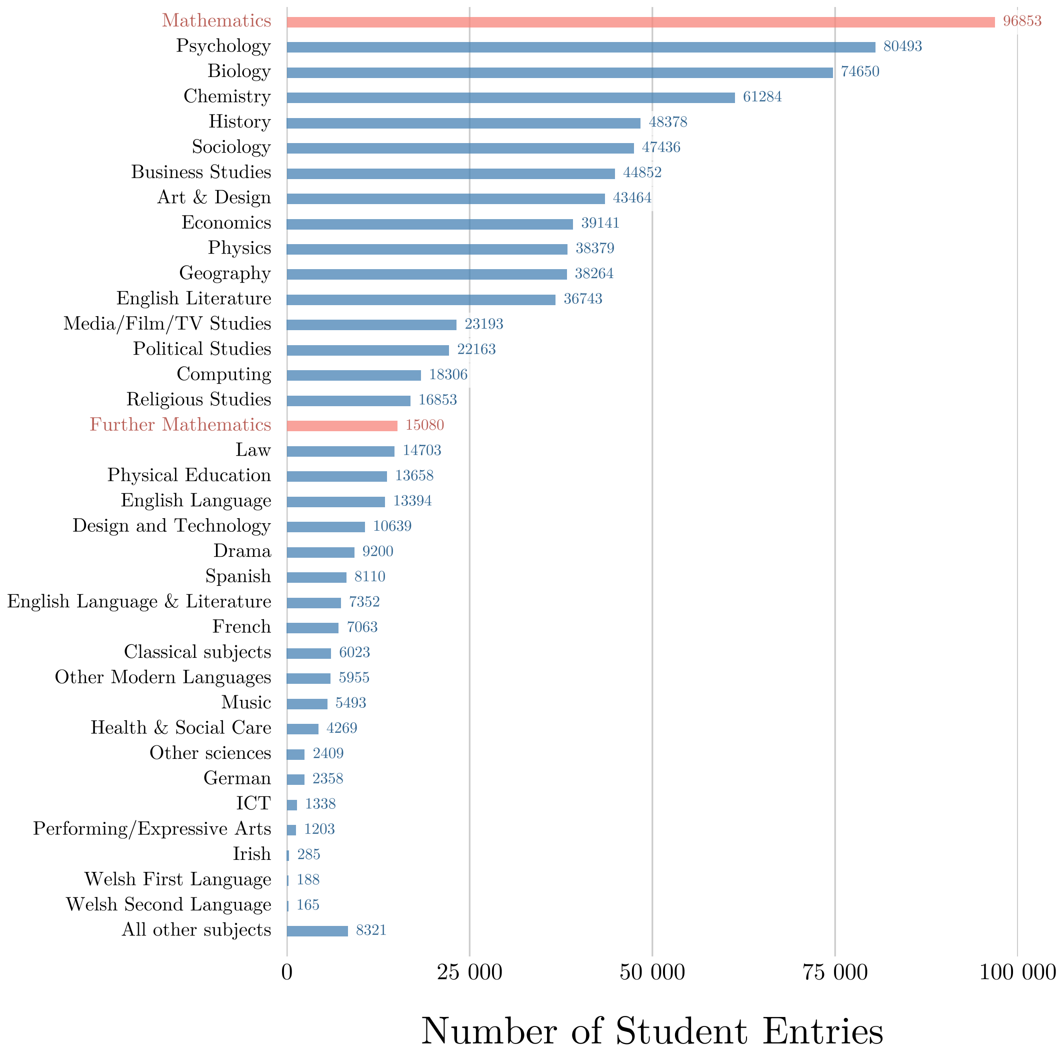


Figure 3.1 | The number of entries in each A-Level subject in 2023 (JCQ, 2023).

Firstly, most Further Education colleges stipulated that a minimum grade of Level 7 (some colleges allow Level 6) in GCSE Mathematics must be achieved in order to progress on to A-Level Mathematics (Noyes & Adkins, 2016). This was due to its higher level of difficulty meaning that only top-achieving students are likely to go on to achieve success (Matthews & Pepper, 2006). However, it is important to note that a pass grade in GCSE Mathematics is a

Level 4, so this potentially means that 46.5% of GCSE students who passed GCSE Mathematics with a Level 4–6 were prevented from studying A-Level Mathematics. This left only 18.4% of GCSE students who passed GCSE Mathematics with a Level 7–9 that could progress to A-Level Mathematics. Of an average of 138 616 students who passed GCSE Mathematics with a Level 7 or higher between 2017 and 2022, an average of 95 393 (or 68.8%) of these students progressed to do A-Level Mathematics (see Table 3.2 for a overview of this data). One should note that these percentages are designed for illustration purposes as they implicitly use the assumption that all GCSE students progress onto A-Levels rather than other post-16 pathways; for context, around 790 000 students take GCSEs and 300 000 students take A-Levels nationally each year (JCQ, 2023; UK Government 2022). Whilst one could argue that the higher level of mathematics content which is studies in A-Level mathematics justifies the higher GCSE Mathematics grade required, it does mean that viable alternative post-16 qualifications should be in place for anyone who wishes to take a mathematics qualification after the age of 16.

Table 3.2 | The number of students who took and passed GCSE Mathematics as well as the number of students who took AS- and A-Level Mathematics using national data from the whole of the UK (JCQ, 2023).

Year	GCSE Mathematics							A-Level Mathematics	
	Total Students	Passed With Grade 4–9		Passed With Grade 4–6		Passed With Grade 7–9		AS-Level	A-Level
2022	782 783	508 026	(64.9%)	352 252	(45.0%)	155 774	(19.9%)	15 489	95 635
2021	746 880	516 841	(69.2%)	362 984	(48.6%)	153 857	(20.6%)	14 466	97 690
2020	749 567	499 212	(66.6%)	356 794	(47.6%)	142 418	(19.0%)	18 363	94 264
2019	720 098	429 178	(59.6%)	314 683	(43.7%)	114 496	(15.9%)	25 923	91 895
2018	747 169	446 807	(59.8%)	329 502	(44.1%)	117 306	(15.7%)	81 051	97 627
2017	770 034	530 553	(68.9%)	382 707	(49.7%)	147 847	(19.2%)	160 450	95 244
Average	752 755	488 436	(64.8%)	349 820	(46.5%)	138 616	(18.4%)	52 624	95 393

Note: Shown in brackets are the number of students who passed with the stated grade as a percentage of the total number of GCSE Mathematics students. The final row corresponds to the mean average of each respective column. Data is given from 2017 as this is when the reforms to the education system changed the grading system to use numbers (9-1) instead of letters (A*-G).

Other difficulties surround the perceived usefulness of the A-Level Mathematics content for future career plans. We see that some university's aim their messaging at endorsing particular choices of post-16 subjects to take (Russell Group, 2019; University of Cambridge, 2022). Also, Homer et al. (2020) found that a motivating reason for students taking post-16 mathematics subjects is because they were told by teachers that it would help with other post-16 subjects. This evidence suggests that a number of students are willing to take a post-16 mathematics qualification on the promise of it making other aspects of their education easier. However, one could argue that some topics in A-Level Mathematics (e.g., advanced calculus, sequences and series, numerical methods) are only likely to directly benefit those looking to study mathematics further such as in a STEM or highly numerate degree such as mathematics, physics or economics at university. Indeed, Demack et al. (2019) found that students studying A-Level Mathematics in England were also likely to take other similar STEM-related subjects at A-Level such as Chemistry, Biology, Physics or Economics with fewer students opting for subjects such as A-Levels in History or English literature.

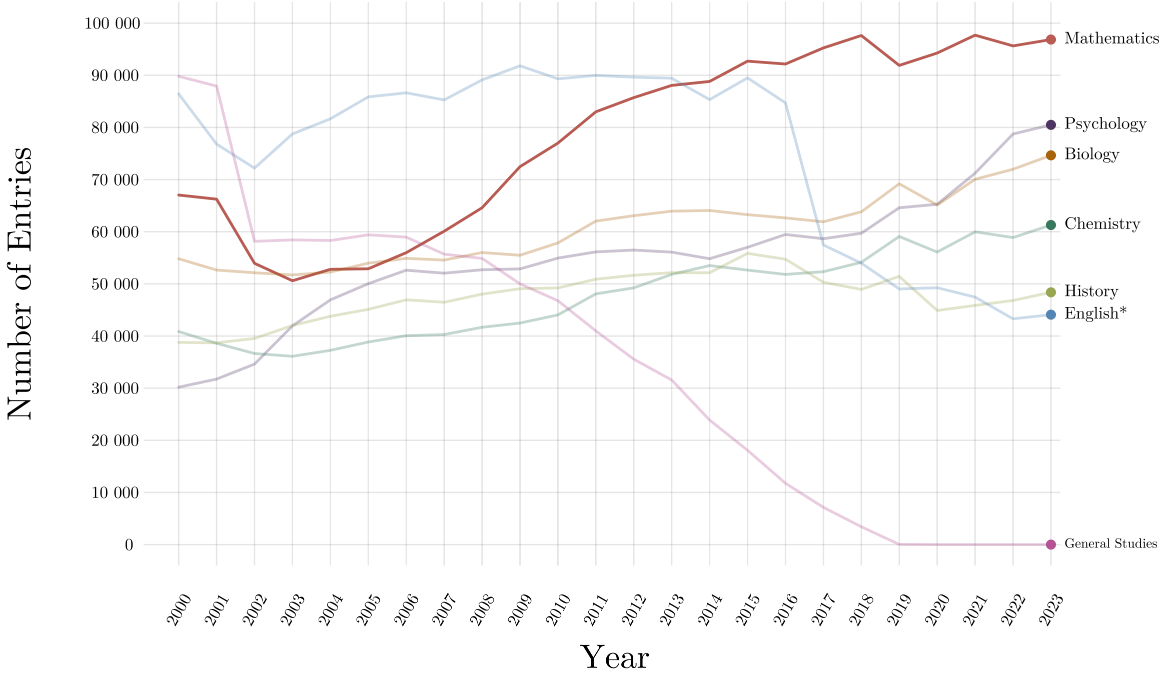


Figure 3.2 | The A-Levels which were ranked at some point as the five most-popular in each year since Curriculum 2000 (JCQ, 2023).

*Note that A-Level English was separated into A-Level English Literature and A-Level English Language and Literature in 2017 and so shown here are aggregated figures of both A-Levels from 2017 onwards.

As an alternative, some students may benefit from the types of quantitative skills which mathematics promotes if they are solely seeking ways to aid other subjects. Thus one can conclude that whilst A-Level Mathematics should be encouraged for those with a vested interest in the subject or those who wish to continue with a mathematics-based career after Further Education, it should not be advertised as a means for everyone who wishes to advantage other aspects of their education (either at Further Education or at Higher Education). This creates a case for other post-16 mathematics options to be made available alongside A-Level Mathematics.

Table 3.3 | A comparison of the total number of A-Level students (UK Government, 2022) and the numbers of students taking A-Level Mathematics and A-Level Further Mathematics (JCQ, 2023) in England for the years 2010 to 2022.

Year	**Total Number**	**A-Level Mathematics**		**A-Level Further Mathematics**		
		Number	Percent of Total	Number	Percent of Total	Percent of Mathematics
2022	283 754	88 316	31.1%	14 284	5.0%	16.2%
2021	267 487	90 047	33.7%	14 811	5.5%	16.4%
2020	261 809	87 252	33.3%	14 138	5.4%	16.2%
2019	260 208	84 965	32.7%	13 730	5.3%	16.2%
2018	260 494	90 189	34.6%	15 279	5.9%	16.9%
2017	316 087	87 679	27.7%	15 303	4.8%	17.5%
2016	323 134	84 606	26.2%	14 484	4.5%	17.1%
2015	266 138	85 648	32.2%	14 298	5.4%	16.7%
2014	257 390	82 024	31.9%	13 402	5.2%	16.3%
2013	261 468	81 171	31.0%	13 232	5.1%	16.3%
2012	262 003	78 951	30.1%	12 688	4.8%	16.1%
2011	258 892	76 528	29.6%	11 805	4.6%	15.4%
2010	267 345	70 654	26.4%	11 312	4.2%	16.0%

Note: Percent of Total is the percentage of A-Level students who are taking the subjects Mathematics and Further Mathematics. Nearly all students taking A-Level Further Mathematics will also be taking A-Level Mathematics. As such, *Percent of Mathematics* represents the percentage of A-Level Mathematics students also taking A-Level Further Mathematics. This data represents summer examinations of the given year (including resit students). In the years 2020 and 2021, additional autumn examinations were offered due to the disruption caused by COVID-19, however these examination series only accounted for a small number of students relative to the respective summer examinations. The data given here refers to students in **England only**, however the number of students taking A-Levels in Wales and Northern Ireland are small relative to England and so this data is only expected to vary by a small amount if extended to the rest of the UK e.g., the number of students taking A-Level Mathematics in 2022 was 88 316 (England only) compared to 95 635 (whole of the UK).

3.3.4 A-Level Further Mathematics

A-Level Further Mathematics is available to students already taking A-Level Mathematics, and might be particularly useful for students looking to continue to a university degree course where there will be a large amount of mathematics. Subject content is often similar to a first-year degree course in a university mathematics subject and MEI (2014) showed that almost 60% of applicants accepted to a degree course in mathematics in 2014 had an A-Level in Further Mathematics. This was furthered by Lee et al. (2017) who found that 12% of the university degree courses which they surveyed, 12% of them required A-Level Further Mathematics, and a further 19% preferred or encouraged students to have the qualification. Each year, around 15 000 A-Level Mathematics students choose A-Level Further Mathematics as an A-Level which is around 5% of the total number of A-Level students in England (Table 3.3).

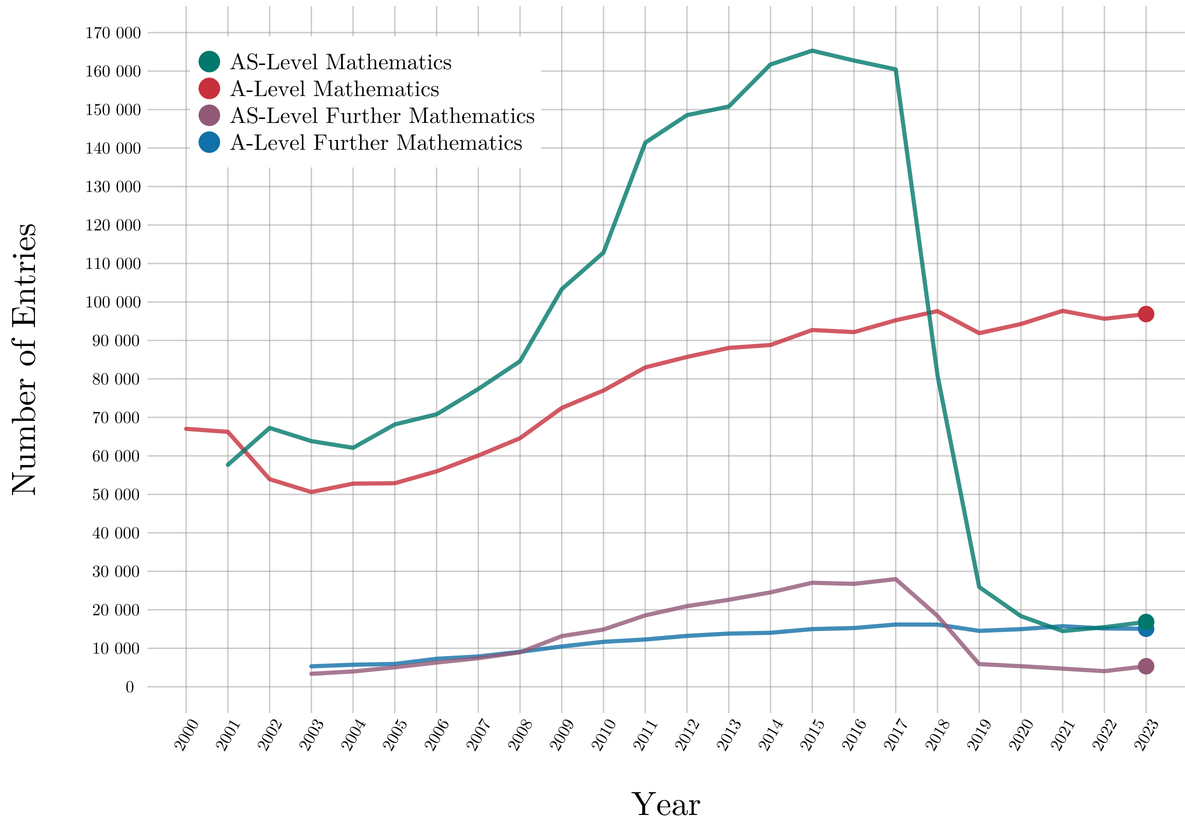


Figure 3.3 | The uptake of AS- and A-Levels in Mathematics and Further Mathematics since Curriculum 2000 (JCQ, 2023).

3.3.5 A-Level Use of Mathematics

In 2009, an A-Level qualification was introduced named Use of Mathematics with pilot status offered in a small number of chosen Further Education colleges. The intention of the qualification was to utilise many of the core topics and ideas seen in AS-/A-Level Mathematics such as algebra, calculus, mechanics, statistics, decision mathematics, numerical methods, but to teach these in a way that emphasised how such mathematics could be useful in a real-world context. Initial concerns about this qualification were noted early, with particular objections from Higher Education explicitly stating that the content was below the required difficulty of a Level 3 qualification in mathematics (Curtis, 2009). The same individuals also argued that the mathematics was obscured behind overly contrived exercises that encouraged learners to use the mathematics content as an algorithmic process rather than critically analysing the ideas in order to develop creativity and proficiency in the subject. Arguments from Higher Education also claimed that the qualification's structure – in particular, that it was offered as a standalone AS-/A-Level qualification – might mislead uninformed students who had the intention of continuing to a mathematics-based subject at Higher Education that they could take Use of Mathematics as an easier pathway towards studying their chosen degree subject. It is important to note, however, that this was never the intention of the qualification. Instead, Use of Mathematics was designed for degree courses that required some mathematics skills and literacy (e.g., social science subjects), however for degree courses that required a high level of competency in mathematics (e.g., STEM subjects), A-Level Mathematics should be chosen instead. For the few colleges that did teach Use of Mathematics, it was mostly a positively received qualification both by learners and teachers since it gave learners the opportunity to study mathematics skills and content beyond GCSE level as well as gaining recognition by Higher Education within applications and offers (Homer et al., 2020). However, partly due to its poor uptake by Further Education colleges, in 2018, A-Level Use of Mathematics was withdrawn and is not currently available to students as a post-16 qualification.

3.3.6 A-Level Statistics

An AS- and A-Level qualification in Statistics is currently offered as a post-16 mathematics qualification. Its history has been challenged by a low uptake from students, with only 731 students (JCQ, 2023) choosing to take the subject with the exam board Assessment and Qualifications Alliance (AQA) in 2016. As a result of this low interest, AQA decided to discontinue offering this post-16 qualification to new learners as of 2016. Not content with this decision, Peter Diggle, the then president of the Royal Statistical Society, put forward arguments to the then Secretary of State for Education, with the primary argument emphasising the importance of statistics for developing analytical and data skills for the workplace and further studies in a range of subjects (Royal Statistical Society, 2016). Advocates of the qualification also underlined the importance of having an alternative two-year qualification that sat besides A-Level Mathematics. As a consequence of the lobbying by the Royal Statistical Society and other organisations, A-Level Statistics was resurrected and first taught by the exam board Edexcel in 2017 with 751 students taking A-level Statistics in 2022 (JCQ, 2023).

3.3.7 Core Mathematics

Introduced in 2015, Core Mathematics is an umbrella term for a set of post-16 mathematics qualifications which was developed with employers and Higher Education in mind. Whilst a maximum of 80% of the content should utilise methods and techniques similar in difficulty to GCSE Mathematics, there is a heavier emphasis on real-world applications with skills such as problem solving, modelling, finance and working with data (DfE, 2013). Core Mathematics is intended to be studied alongside an existing A-Level course as either a one- or two-year qualification and, although intended for students who have passed GCSE Mathematics but not studying an AS-/A-Level Mathematics, it is recognised as a Level 3 qualification equivalent in UCAS tariff points to an AS-Level (see Table 3.4 for information about UCAS tariff points). This allows for flexibility in how colleges choose to teach the qualification and allows students the opportunity to study some form of post-16 mathematics where they may otherwise have chosen not to (Homer et al., 2020).

Despite the positive sentiments of Core Mathematics, the qualifications have faced challenges, particularly regarding their uptake (Figure 3.4). For instance, Core Mathematics initially had 2 931 students taking the first examinations in 2016, however this only rose to 12 367 in 2023 (MEI, 2023). This 2023 data accounts for only 6% of the estimated 200 000 A-Level students that have passed GCSE Mathematics but choose not to take an A-Level in a mathematics subject. In some cases, (Homer et al., 2020) found that some Further Education colleges decided not to continue offering Core Mathematics to their students beyond the pilot stages. This does not provide an optimistic outlook on the government's aims to increase the number of students studying post-16 mathematics (Department for Education (DfE), 2011; A. Smith, 2017) and there is an identified need to drastically boost these numbers if Core Mathematics is one of the potential solutions to help achieve this. Homer et al. (2020) highlighted that the slow recognition of Core Mathematics from Higher Education institutions played a major role in whether Further Education colleges offered it to their students and whether students were willing to take the

Table 3.4 | The UCAS tariff points that can be awarded for post-16 qualifications depending on the grade achieved by the student (UCAS, 2023). These tariff points can be used by Higher Education institutions to determine whether an applicant has reached the minimum entry requirement for their degree courses.

Grade	A-Level	AS-Level	Core Mathematics	FSMQ	EPQ	T-Level	BTEC
A/Distinction**	56	–	–	–	28	56	56
A/Distinction	48	20	20	10	24	48	48
B	40	16	16	8	20	40	40
C/Merit	32	12	12	6	16	32	32
D	24	10	10	5	12	24	24
E/Pass	16	6	6	3	8	16	16

An A-Level, AS-Level, Core Mathematics, FSMQ and EPQ are graded using letter grades, whereas a T-Level and BTEC are graded using Distinction(*), Merit, Pass. The maximum grade awarded for an AS-Level, Core Mathematics and FMSQ is A. BTEC qualifications consist of two components (BTEC Diploma) or three components (BTEC Extended Diploma) whereby each individual component is graded and awarded the respective UCAS points. Similarly, T-Levels consist of three components which are each graded and awarded the respective UCAS points. This means that a single BTEC or T-Level qualification could be awarded a maximum of $3 \times 56 = 168$ UCAS points in the event that a Distinction* is awarded for all components.

additional qualification. Glaister (2015b) complemented this with a summary of statements on Core Mathematics from universities admissions. The author found that 45 universities provided messaging which supported applicants with Core Mathematics, with five of these universities (University of Exeter, University of York, University of Bath, University of Sheffield, Keele University) offering a reduced entry requirement i.e., they will offer a reduction in the required A-Level grades if an applicant has achieved a pass grade in Core Mathematics. Since universities update their course pages regularly, where possible, we also searched the 45 individual university's web pages ourselves in February 2023 to corroborate these findings and to ensure that the most up-to-date statements are summarised here. In some cases, we were unable to find statements about Core Mathematics and so elected to use the statements provided by Glaister in these instances. This updated list is provided in Section D.3 and we have summarised alternative grades and reduced offers in Table 3.5.

19 of these universities specified that they would accept Core Mathematics as an alternative to GCSE Mathematics. Whilst it is positive that these universities recognise that Core Mathe-

Table 3.5 | University Statements on Core Mathematics revised from Glaister (2015b).

University	Reduced offer	Level 2/3 mathematics					
		In lieu	AS Maths	GCSE A/7	GCSE B/6	GCSE C/4	Not Explicit
University of Manchester	–	–					
London School of Economics, University of London	–	Yes					
Queen Mary, University of London	–	Yes					
University of Southampton	–	–					
University of Exeter	Yes	–					
Lancaster University	–	Yes					
University of Birmingham	–	Yes					
Loughborough University	–	–					
Aston University	–	–					
Royal Holloway, University of London	–	Yes					
Coventry University	–	–					
Leeds Beckett University	–	–					
University of York	Yes	–					
University of Newcastle	–	Yes					
University of Hull	–	–					
University of Buckingham	–	–					
Nottingham Trent	–	Yes					
University of Sunderland	–	Yes					
University of Surrey	–	Yes					
University of Warwick	–	Yes					
University of Bath	Yes	–					
Harper Adams University	–	–					
University of Kent	–	–					
University of Sheffield	Yes	–					
University of Essex	–	–					
Goldsmiths, University of London	–	–					
University of Leeds	–	Yes					
University of Leicester	–	Yes					
Cardiff University	–	Yes					
University College London	–	Yes					
University of Liverpool	–	–					
Sheffield Hallam University	–	–					
University of Brighton	–	–					
City, University of London	–	–					
University of Durham	–	Yes					
University of Edinburgh	–	Yes					
Imperial College, London	–	–					
University of Reading		–					
University of Nottingham	–	Yes					
King's College London	–	Yes					
University of Cambridge	–	–					
Keele University	Yes	–					
University of Plymouth	–	–					
University of Central Lancashire	–	–					
University of Bristol	–	Yes					

Note: This list summarises the universities which mentioned Core Mathematics according to Glaister (2015b). The green shaded cells indicate the qualification/grade which Core Mathematics can be used in lieu of (note that this may be dependent on a specific grade being achieved in Core Mathematics). The University of Surrey, stated that they would accept Core Mathematics in lieu of an equivalent qualification, but they did not explicitly state which qualification. Most universities specified a letter grade for GCSE Mathematics (A*-C) so we have made a conversion to the updated number grades (9-1).

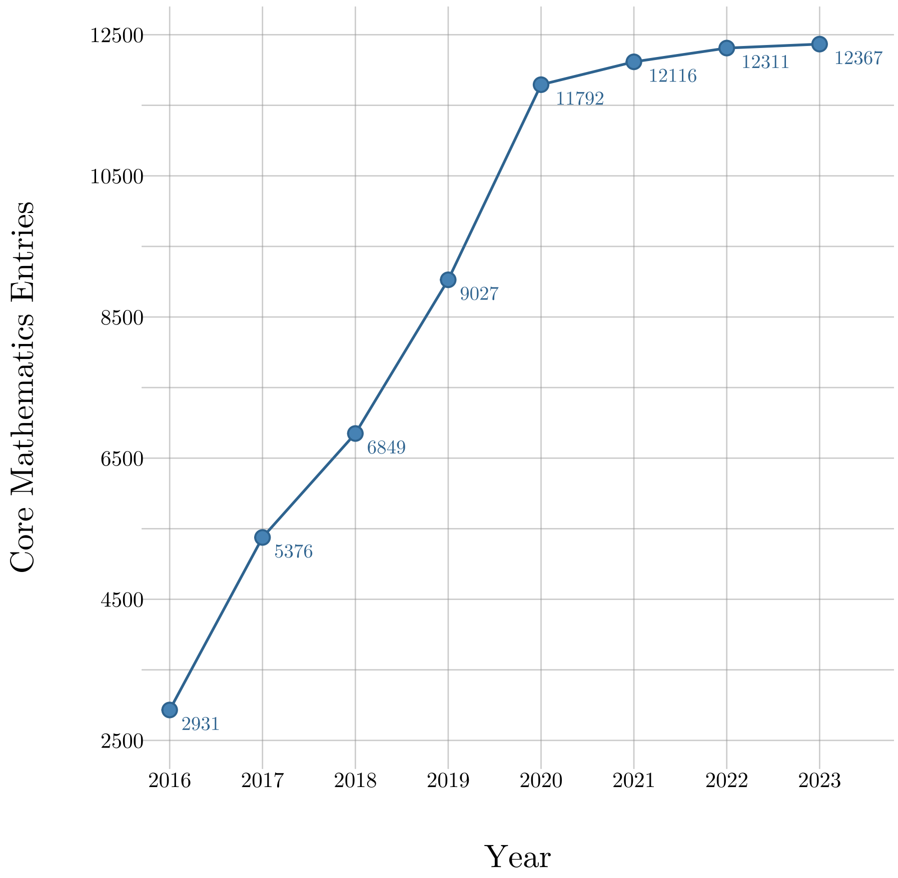


Figure 3.4 | The uptake of Core Mathematics given by student entries in the first exam series in 2016 until the most recent exam series in 2023.

matics gives them some information about an applicant's level of mathematics ability, the fact that they are comparing Core Mathematics (a Level 3 qualification) as an alternative for GCSE Mathematics (a Level 2 qualification) could give conflicting messaging about the value of the qualification, especially given that Core Mathematics is designed for students who have already passed GCSE Mathematics. For example, the University of Edinburgh value a Grade A or Grade B in Core Mathematics as a like-for-like equivalent to a Grade A/Level 7 or Grade B/Level 5 in GCSE Mathematics, respectively; placing this information in the GCSE entry requirements section of the website instead of alongside other Level 3 qualifications. Despite this, it is positive to see that some universities value a pass grade in Core Mathematics as higher than a standard pass grade of Level 4/Grade C at GCSE Mathematics (typically, Grade B/Level 5 [e.g., London School of Economics, Royal Holloway, University of Leicester, Cardiff University, University College London, University of Bristol] or Grade A/Level 7 [e.g., University of Durham]). Moreover, some universities (e.g., Queen Mary, University of London, Lancaster

University, University of Surrey, University of Warwick, University of Nottingham, University of Bristol) stated that they will treat a pass grade in Core Mathematics (typically a grade C) as meeting the GCSE Mathematics entry requirements of the course, regardless of the specified GCSE grade.

Harper Adams University arguably gave the weakest messaging towards Core Mathematics in that they recognised that it would be beneficial to students in Further Education who needed to develop their quantitative skills, but gave no indication that they believed that Core Mathematics would be positive for students when studying in Higher Education. University College London also gave no indication of the benefits of Core Mathematics at university, but at least stated that they recognised a pass grade as an equivalent qualification to GCSE Mathematics level 5/grade B.

On the other hand, the university that arguably had the strongest messaging towards Core Mathematics and Level 3 mathematics qualifications in general, is the University of Bath. They were one of the first universities to offer a reduced entry offer for applicants with Core Mathematics and have since revised their messaging to state that if an additional Level 3 mathematics qualification is taken alongside three other required subjects, a reduced grade offer will be made, providing that the applicant achieves a grade B or above in this post-16 mathematics qualification. The reasoning stated by the university is that they recognise the value which additional mathematics can give in terms of quantitative and analytical skills to students when studying at university. In addition, Keele University also provided a strong incentive of up to two reductions in grades for most courses for students who achieve at least a grade B in Core Mathematics. The University of Birmingham were the only university to explicitly state that they will accept Core Mathematics as a direct equivalent to an AS-Level in Mathematics. Although Core Mathematics was never intended as a substitute for AS-/A-Level Mathematics, it is equivalent in UCAS tariff points to an AS-Level qualification Table 3.4 so it is positive to see that the University of Birmingham is recognising this.

(Homer et al., 2020) highlighted that a reason for Further Education colleges being reluctant to offer Core Mathematics to their students is due to the lack of recognition of the qualification at universities. This was also evidenced in the statements given by some of the universities surveyed by (Glaister, 2015b). For example, some universities (e.g., University of Hull, University of Buckingham, Coventry University, University of Southampton) stated that their reasoning for not considering Core Mathematics as part of their entry offer is that it is not widely available in Further Education colleges. Whilst it might seem fair that these universities did not want to discriminate against such students, one must ask the question that if Further Education colleges are tentative to offer Core Mathematics unless universities show positive recognition of it and universities are reluctant to offer reduced entry requirements unless more Further Education colleges widely offer the qualifications, how will this cycle be alleviated? We also discovered that some of these messages were not easily found on university websites and so students who attempted to independently research the value in taking Core Mathematics as a post-16 option by using these sources may have had difficulty in finding this information and thus infer negative conclusions about how universities value it. One potential reason for this could be that universities are waiting to find evidence that such qualifications benefit their students before providing significant endorsement as part of their application process. Whilst our research did not aim to look specifically at Core Mathematics, we did investigate the effect of post-16 mathematics when students start at university and so our evidence may contribute in part towards this.

3.3.8 Free Standing Mathematics Qualification (FSMQ)

FSMQs are standalone qualifications that tend to be taught alongside other subjects at either Secondary Education or Further Education level and are intended to make the transition between GCSE and certain post-16 mathematics qualifications (e.g., AS-/A-Level Mathematics, Core Mathematics) easier. They come in three levels – Foundation, Intermediate and Advanced – that correspond to Level 1, 2 or 3 in education standards (see Table 1.1). An Advanced level FSMQ is roughly equivalent to half an AS-Level (see Table 3.4). As of 2023, the exam board OCR are the only awarding body still offering a single module of this qualification, with AQA withdrawing from the pilot Advanced level FSMQ in 2019. This is partly due to the regulations put in place by the Department for Education regarding vocational qualification and how they are reported in performance tables (FE Week, 2011).

3.3.9 Extended Project Qualification (EPQ)

Some Further Education colleges give their students the opportunity to study for an EPQ alongside their A-Levels. It is an independent research project equivalent to half an A-Level which allows learners to build skills such as problem solving and critical thinking (e.g., see AQA 2019 specification). A student will initially have 30 hours of guided learning to build the skills necessary to complete the EPQ and will then subsequently select a topic to research that will form the remaining 90 hours of their EPQ under the guidance of a course leader. There are few limitations on the choice of this topic, however the final assessed piece of work (typically a written essay, although other pieces may be presented for assessment) must be to a Level 3 standard (OCR, 2023). Due to the level of flexibility of an EPQ, a student may choose to undertake a mathematics-related project to either complement their existing post-16 mathematics studies, or, indeed, to act as an alternative to taking a post-16 mathematics subject. For example, widely regarded as a prestigious set of summer schools, Oxford Royale, provides 600 research topic ideas for students undertaking EPQs with 25 of these ideas focused on mathematics (Oxford Royale, n.d.). Universities positively favour the EPQ with some offering reduced entry requirements if a student has undertaken an EPQ (e.g., Queen Mary University of London, University of Southampton, University of Bath, University of Sheffield, University of Leeds). Whilst an EPQ is a potential source of encouraging investigation into mathematics, since there is no stipulation over which subjects need to be chosen, it is arguably unlikely that an individual not studying a post-16 mathematics-related subject will go on to choose an EPQ in this area. In addition, the skills utilised in an EPQ revolve more around research and so researching a mathematics-related topic is unlikely to elicit the same quantitative skills that other post-16 mathematics options can provide.

3.3.10 Embedding Mathematics in Existing Post-16 Qualifications

As part of the education reforms laid out in 2014 by the Department for Education, there was an emphasis that certain AS-/A-Level subjects should be able to demonstrate a specific percentage of mathematics skills and knowledge at Level 2 (GCSE) standard or above. Example mathematical content is provided in the relevant subject guidance provided by UK Government (2017) and an overview of the minimum percentage of assessed mathematical content is stated in A. Smith (2017) (page 41). Most of the 14 AS-/A-Level subjects listed in A. Smith (2017) had a proportion at or below 20%, however AS-/A-Level Geography, Electronics and Physics were the highest ranking in terms of proportion of mathematical content. The common mathematical skills between these subjects emphasised statistical themes related to the handling of data, whilst some required numerical or algebraic calculations.

Adkins & Noyes (2018) proposed that embedding content within a student's preferred subjects may lead to more success with learning mathematics skills than if these same skills are taught explicitly and out of context. This work was furthered by Norris & Noyes (2023) who surveyed the technical documents of 19 A-Level subjects which are listed to require quantitative content according to the overarching General Mathematical Competencies (GMC). Subjects included environmental science, psychology and sociology as well as mathematics and further mathematics. The authors found that processing data had the highest frequency of all GMCs with all subjects surveyed requiring at least one of its sub-competencies, however understanding data and risk and communicating using mathematics also had a high frequency and their sub-competencies were required by all subjects. Of all the GMCs, costing and optimising work processes had the lowest frequency, perhaps due to its specialist nature and difficulty to integrate into subjects such as A-Level Biology or Sociology without using overly contrived examples. The authors also explored combinations of A-Level subjects which exhibited a high range of GMCs and, thus, quantitative skills. Whilst studying A-Level Mathematics or Further Mathematics obviously gave a high level of quantitative skills, they argued that combinations such as Geography, Psychology and Sociology still gave coverage of a wide range of GMCs, but it would do so in an applied context without the necessity of studying formal mathematics content.

It is apparent that the decision by the Department for Education to embed important quantitative skills within an individual's chosen AS-/A-Levels means that students should be able to see the direct relevance between important mathematics and statistics skills and its applications in real-world contexts. It also means that it is no longer necessary to view A-Level Mathematics and Further Mathematics as the sole provider of these skills in Further Education. Indeed, the fact that GMCs related to using and interpreting data appear frequently in these technical documents indicates how a wide range of subjects value these quantitative skills. For the purposes of this research, it is important to understand that post-16 mathematics permeates through a range of other subjects in addition to mathematics. As such, we aim to explore a range of degree subjects at university which are likely to rely on a wide scope of quantitative skills in different ways.

3.4 Post-16 Mathematics Funding Initiatives

To complement the choice of post-16 mathematics pathways available to learners in Further Education, various funding initiatives have been put in place to both drive uptake and support learning and teaching in post-16 mathematics. This complements one of the recommendations of the Smith Review (A. Smith, 2017) which recommended that more funding was made available to increase uptake of post-16 mathematics.

- **Advanced Mathematics Premium** (UK Government, 2023a) introduced in 2018 and will award Further Education colleges with funding for each additional student taking a Level 3 mathematics qualification.

- **High Value Courses Premium** (UK Government, 2023b) has been in place since 2019 and will award Further Education colleges funding for each student studying combinations of certain A-Level subjects. These include A-Level Mathematics, Further Mathematics and Statistics.

- **Large Programme Uplift** (UK Government, 2023c) has been in place since 2014 and encourages competent students to take additional A-Levels beyond the traditional three. It allows Further Education colleges the opportunity to receive money back per student for every student achieving at least a Grade B in all four or five of their A-Levels, or a Grade C for A-Level Further Mathematics.

- **Advanced Mathematics Support Programme (AMSP)** (AMSP, 2021), building upon previous work by the Further Mathematics Support Programme (FMSP) and the Core Mathematics Support Programme (CMSP), is a government-funded initiative that provides support for teachers and students as well as to encourage students to take post-16 mathematics. This is occasionally partnered with work by the National Centre for Excellence in the Teaching of Mathematics (NCETM) (NCETM, 2023) which was formed in 2006 after the Smith Report (A. Smith, 2004) and aims to support mathematics teaching. Among its goals is the increase in the provision of post-16 mathematics teachers, including Level 3 qualifications such as A-Level Mathematics and Core Mathematics and Level 2 GCSE Mathematics retakes after the age of 16.
- **Core Mathematics Premum** (UK Government, 2024) was introduced in Februray 2024 as an initiative to encourage uptake of Core Mathematics qualifications between the ages of 16-18. The funding allows Further Education colleges to claim £900 for each student that takes the qualification, although students are not ellible to receive both the Advanced Mathematics Premium *and* the Core Mathematics Premium.

These funding initiatives have been shown to be successful in increasing the number of students studying post-16 mathematics. For instance, the Advanced Mathematics Premium provided 966 providers over £16 million in the academic year 2021-2022, resulting in an increase of 27 000 students studying some form of post-16 mathematics compared to the five years prior. In addition, the High Value Course Premium paid out over £84 million to 2 153 providers in the academic year 2021-2022 (AMSP, 2022). Whilst the evidence shows that these funding initiatives are clearly somewhat successful at getting more students to take post-16 mathematics, they rely on Further Education colleges to encourage learners to enrol in these qualifications in the first place. Since the funding goes to the college and not directly to the students, the students also need some form of incentive to want to take post-16 mathematics. Evidence shows that universities can be a successful driver of uptake here (e.g., Lee, Saker & Baldwin, 2017; Homer et al., 2020) and so funding initiatives alone are unlikely to bridge the "mathematics gap" (DfE, 2013). Indeed, 27 000 additional learners within five years (AMSP, 2022), whilst positive, is still a long way from the estimated 200 000 A-Level students not taking any form of post-16 mathematics (Homer et al., 2020).

3.5 Demand for Mathematics in Higher Education

A main focus of this research was to investigate the effect of varying mathematics skills of students at university. Specifically, we looked at undergraduate students when starting at university. However, to what extent do universities recognise that there is a need for students to have quantitative skills when studying their degrees? In this section we aim to outline this question by reviewing some of the initiatives and information related to this.

3.5.1 Entry Requirements

One immediate way to measure how universities regard quantitative skills is by considering university entry requirements. For instance, if communication is given regarding the expected level of quantitative skills prior to applying for a degree, then this will be a clear indication that universities recognise their importance. However, the evidence suggests that this is not the case. Lee et al. (2017) cited that of the 757 STEM and STEM-related degree courses that they surveyed, 56% required A-Level Mathematics with only 3% of the remainder providing messaging that preferred or encouraged it.

In addition, the Smith Review highlighted a finding by Dawson (2014) which stated that 80% of students on economics degrees underestimated the quantity of mathematics that would be studied. This leaves questions over how informed students are about the level of mathematical demands that are required of them when starting their degree. If the messaging is not clear, then students will naturally have mixed understanding over which post-16 subjects to take, as Hodgen et al. (2020) showed that most students look to universities or their future career plans when deciding which subjects to take between 16-18.

3.5.2 Quantitative Skills at University

To provide evidence of the extent to which university degree courses require quantitative skills, we obtained an overview of all 244 first-year undergraduate modules which were taught across all departments at the University of Essex in the academic year 2022-2023. We did this by using the department timetables to source an exhaustive list of all first-year modules. We then manually searched each module's web page and read the description of the module in order to make an assessment of whether quantitative skills are part of the taught content. Whilst some descriptions were detailed enough to make accurate judgments e.g., by providing an in-depth syllabus, others simply listed the broad key skills or learning outcomes and so we only included a module if explicit reference to quantitative skills or knowledge such as data analysis or numerical calculations were mentioned. Our survey found that there were 77 modules (32% of all modules surveyed) which listed some form of quantitative skill. This accounted for 10 out of the 18 departments at the University of Essex which taught at least one module that involved quantitative skills to their first year undergraduate students. We found that popular quantitative skills involved analysing and presenting quantitative data, however other skills such as performing numerical calculations and financial skills were also listed. A full list of the 77 modules teaching quantitative skills and their broad quantitative content can be found in Section D.2. We note that this overview only specifies first-year undergraduate modules since this is the focus of our research, and so we are mindful that some departments may instead teach modules with quantitative skills in the second- or third-year of an undergraduate degree course. We also do not intend for this to be an in-depth survey of all quantitative skills in these modules as some of these web pages may not list all of the content which is taught. These findings do, however, illustrate that quantitative skills are integrated as part of a wide range of degrees at the University of Essex and so it is necessary to understand factors which contribute towards their success.

To reinforce these findings that some degree schemes have quantitative skills embedded in their syllabus, the University of Essex currently requires that a 30-minute online numeracy diagnostic assessment is taken in the first week of term if students do not have an AS-Level or A-Level in Mathematics (University of Essex, n.d.-b). Departments which require this assessment include the School of Life Sciences, School of Computer Science and Electronic Engineering, Department of Economics, Essex Business School and Department of Psychology. Students will then be registered on an appropriate study skills module based on the results of this diagnostic assessment to ensure that they are adequately prepared for the quantitative demands of this module. In addition, the university provides a dedicated mathematics support service which covers fundamental quantitative topics such as algebra, calculus, statistical summaries and hypothesis testing as well assistance with using statistical software such as R and SPSS (University of Essex, n.d.-a).

Whilst this section focuses primarily on the quantitative degree content and support at the University of Essex on the basis that this is where the majority of our studies where conducted, it is clear that quantitative skills play a major role when starting at university. However, in an attempt to review whether this extends to other university institutions, we must look more generally at the requirements which universities have to follow in order to gain accreditation for their degree schemes.

3.5.3 Accredited Bodies

In order for most degree schemes offered at UK universities to gain recognition as a qualification, they need to undergo accreditation from recognised bodies. By analysing the handbooks of such accredited bodies, one can usually find details about the required level of mathematics that is required in particular degrees. For example, the The British Psychological Society (BPS) (2019) states that an accredited degree in a psychology discipline requires graduates to:

> *"Demonstrate a systematic knowledge of a range of research paradigms, research methods and measurement techniques, including statistics and probability, and be aware of their limitations... [and]... analyse, present and evaluate quantitative and qualitative data and evaluate research findings."*

Similarly, the Royal Society of Biology (RSB) (2015) states that the guidelines of an accredited degree in a life sciences discipline requires:

> *"A foundation in mathematics, statistics, chemistry and physics within a biological context appropriate to the discipline. At a basic level all bioscience degrees should integrate mathematics, statistics, chemistry and physics to the extent that knowledge and understanding of science principles governing current techniques and concepts should be embedded within the curriculum. The knowledge and understanding of mathematical principles that support the application of key biological concepts must be sufficient to promote problem solving at the theoretical and practical levels. Students should be equipped with the mathematics needed to handle variation at different levels, especially with regard to the greatly increased amount of data being generated by modern laboratory and computing techniques. Students should understand the statistical aspects of experimental procedures, encompassing the analysis of collected data, the design and analysis of studies, the development of calibration and analysis techniques, and the robustness of data."*

The British Computer Society (BCS) (2022) specifies that in order to obtain Chartered Engineer (CEng) status, degrees in computer science must satisfy five learning outcomes, of which science and mathematics are listed as one. Specifically, one must:

> *"Apply a comprehensive knowledge of mathematics, statistics, natural science and engineering principles to the solution of complex problems. Much of the knowledge will be at the forefront of the particular subject of study and informed by a critical awareness of new developments and the wider context of engineering... Formulate and analyse complex problems to reach substantiated conclusions. This will involve evaluating available data using first principles of mathematics, statistics, natural science and engineering principles, and using engineering judgement to work with information that may be uncertain or incomplete, discussing the limitations of the techniques employed."*

Whilst criteria tends to be vague surrounding the particular types of mathematics content that should be included in an accredited degree, it is important to note that quantitative skills such as data analysis and interpretation are necessary components of the syllabus, with some handbooks (e.g., Royal Society of Biology (RSB) (2015)) stipulating that it must underpin key aspects of the course. This is very much in line with the guidance given in some A-Level courses (see Section 3.3.10) where mathematics skills should be integrated with the existing content and taught in context with subject-related examples. The fact that these handbooks are specifying that quantitative content is necessary in order for a university degree to obtain the necessary accreditation emphasises the importance of these skills at university.

3.5.4 Q-Step Programme

The Q-Step programme was launched in 2013 and was a major initiative with £19.5 million of awarded funding (The Nuffield Foundation, 2023a). Its aim was to encourage university students to do additional mathematics courses which would complement the required quantitative skills in their chosen degree. In particular, the initiative focused on social science degrees where students may not have chosen to do post-16 mathematics previously, but were more likely to need some form of quantitative research skills. The Q-Step programme was designed to enhance the existing degree structure by integrating extra quantitative modules and skills within the syllabus as well as providing opportunities for students to engage with summer schools, workshops and workplace placements. The 18 universities that were chosen to become a Q-Step Centre would have access to the support needed to integrate these quantitative skills in their degree schemes through specialised learning materials or increased teaching capacity. Rosemberg et al. (2022) independently evaluated the Q-Step programme and found success in terms of high satisfaction from students as well as long-term employment benefits such as students graduating with higher levels of quantitative skills needed for research academia and in industry. Indeed, the fact that such a large amount of funding was awarded and that 18 universities had integrated this quantitative programme across a total of 81 degree schemes and 236 modules (The Nuffield Foundation, 2023a), shows that universities themselves recognise the need to increase the quantitative skills among their students.

3.6 The 2017 Smith Review

In 2017, Professor Sir Adrian Smith released a review that was commissioned by His Majesty's Treasury (HMT) and the Department for Education (DfE) and conducted between March 2016 and July 2017 (A. Smith, 2017). The aims of the review were to investigate the effects of the shortage of mathematics skills on the UK economy as well as the provisions which were available to students in Further Education to continue with mathematics pathways beyond the age of 16. The review outlined some key findings as well as making important recommendations for the future of how mathematics education between the ages of 16-18. Since a primary motivating reason for conducting this research described in (Section 1.2) was the release of this government-commissioned review, this subsection aims to summarise the findings and recommendations that are pertinent to this research project.

3.6.1 Key Findings

Throughout the review, the term mathematics was defined broadly as "...mathematical and quantitative skills... [including] numeracy, statistics and data analysis". The review started by making the case for mathematics education, highlighting that there is a widespread shortage of mathematics-based skills in the UK, particularly when compared to other developed countries. It stated that approximately 75% of students with a GCSE pass grade choose not to study mathematics after it ceases to become compulsory which leads to over 40% of UK university students on STEM degrees and over 80% on non-STEM degrees without a post-16 mathematics qualification.. This has implications for university study as well as for the workplace and wider economy with numerically literate individuals found to earn more earnings and be higher in productivity.

The review also reported on demographic differences in those choosing to continue with post-16 mathematics such as geographic (34% of students in London with a pass grade in GCSE Mathematics, compared to just 20% in the North East), ethic (55% of white students with top grades in GCSE Mathematics, compared to 80% of Asian students) and gender (50% of girls with top grades in GCSE Mathematics, compared to 70% of boys).

The Smith Review recognised that many university degree courses require a substantial level of quantitative skill and that post-16 mathematics qualifications may be a viable way of ensuring that such students are better-prepared for their university study. This is further emphasised by the fact that some undergraduate students are surprised by the level of quantitative skills that are required for their respective degree course, noting a finding by (Dawson, 2014) that states that over 80% of Economics undergraduates were surprised by the high quantity of mathematics content in their degree. Indeed, the review picks up on the findings by (Hodgen et al., 2014) which highlights that anxiety and a lack of confidence is a problem when dealing with mathematics-based problems, worsened by the two-year mathematics gap between ages 16-18. The review also highlighted the strong role that universities play on the requirements set by schools and colleges and when learners are deciding which post-16 qualification to take, reflecting the findings of other research in this area (e.g., Lee et al., 2017; Homer et al., 2020).

3.6.2 Key Recommendations

The Smith Review emphasised that post-16 mathematics qualifications should be made more widely available to all learners in order to address the widespread shortage of mathematics skills. In particular, the review highlighted Core Mathematics as a viable post-16 qualification to help achieve this. This qualification is discussed in further detail in Section 3.3.7, although several of the recommendations highlighted that the Core Mathematics brand needs to be made stronger through more teacher training initiatives, including using non-mathematics teachers such as those teaching subjects with quantitative elements. A viable way of making post-16 mathematics provisions stronger is through university recommendations and the positive messaging put out by Higher Education in recognising the value in post-16 mathematics qualifications, particularly to learners starting out on many Higher Education courses.

In addition, the review highlighted that better advice needs to be given to young people about the importance that mathematics has in a wide range of careers. Among these is the rise of data science and so further understanding is needed regarding the mathematics and quantitative training needed to support this.

3.6.3 Impact for this Research

The Smith Review highlighted the shortage of students with post-16 mathematics qualifications in the UK which leads to a shortage of mathematics skills for Higher Education and industry. The high proportions of students who have not studied mathematics in the so-called "mathematics gap" (DfE, 2013) between the ages of 16-18 means that students come to university courses with a limited ability in mathematics which leads to students at university lacking in confidence and more anxious when completing quantitative tasks. As shown in Section 3.5.2, a large proportion of university students are expected to study quantitative content, even if they are not doing a STEM-based degree. This is despite some of these degree courses having no prerequisite of a post-16 mathematics qualification (Lee et al., 2017).

This shortage of mathematics skills also puts the UK at a disadvantage when compared to other countries. In other countries such as Canada, Ireland, Japan, Korea, Sweden, and the USA, the uptake of post-16 mathematics is generally over 50%, whereas the UK is only 20% (Hodgen et al., 2010).

The Smith Review repeatedly reported the problems faced by learners in Higher Education, citing a lack of confidence and high levels of mathematics anxiety when dealing with mathematics-based problems, made worse when learners have potentially not studied any substantial mathematics since the age of 16. This gives motivation for additional factors to explore as part of our research.

3.7 Mathematics Pathways in the UK: A Discussion

There is clear evidence that students look to universities when choosing which post-16 options to take (e.g., Russell Group, 2019). Since 2014, it is compulsory for students in England to remain in education or employment training until the age of 18, however there is also a wide range of potential pathways that students can take. These also include post-16 mathematics options both as standalone qualifications (such as AS-/A-Level Mathematics, Statistics and Further Mathematics) and as elements that integrate key mathematics skills within an existing course (see Section 3.3.10). Despite this, there is still a clear mathematics shortage with the UK falling behind other comparable countries in terms of mathematics studied between the ages of 16-18 (The Nuffield Foundation, 2023b) which leads to the so-called "mathematics gap" (DfE, 2013). As such, new post-16 qualifications such as Core Mathematics have been introduced in order to entice a greater number of students to take mathematics, however its uptake has failed to address the clear shortage of students not taking any form of post-16 mathematics since its introduction with some placing responsibility on Higher Education institutions and their lack of widespread positive messaging given to students (Homer et al., 2020).

In 2017, the Smith Review (A. Smith, 2017) conducted a review into 16-18 mathematics provisions and found that the low uptake of learners choosing to take mathematics after the age of 16 likely exacerbated high levels of mathematics anxiety and low levels of confidence when meeting situations involving mathematics in later life, such as at university. Indeed, the review made recommendations to the UK government that included funding initiatives and a greater choice of post-16 mathematics options to be made available to learners in Further Education. This has since been picked up with some funding initiatives proven to be successful at increasing uptake (Advanced Mathematics Support Programme (AMSP), 2022), however there is a long way to go to meet the high number or learners not taking a post-16 mathematics option. In addition, aims set out by the UK government to make post-16 mathematics study compulsory such as that by Education Secretaries (DfE, 2011) and the Prime Minister (UK Government, 2023e) are, at the time of writing this thesis, yet to materialise into tangible policies. However, in December 2023, the UK Government announced plans for an Advanced British Standard which could change the way in which learners study within Further Education. For example, the plans state that there will be the compulsory study of five prescribed subjects, including mathematics, which reflects a baccalaureate system (DfE, 2024).

We believe that this shortage of mathematics skills has implications for students when transitioning to university. Our survey of all first-year undergraduate modules at the University of Essex in the academic year 2022-2023 showed that around a third of all modules involved some form of quantitative skills such as data analysis or numerical calculations. This accounted for

10 out of 18 departments which taught at least one module with quantitative skills. Indeed, the accreditation handbooks such as the (The British Psychological Society (BPS), 2019) and (Royal Society of Biology (RSB), 2015) placed emphasis on data analysis and interpretation as necessary skills to underpin aspects of an accredited degree in these fields. In addition to this, the Q-Step programme aims to increase the quantitative literacy of students in social science degrees by supporting the provision of teaching and module content in these areas. However, what is missing from this narrative is the effect that the shortage of post-16 mathematics skills has on students when they start at university. As such, our research aims to provide evidence in this direction.

4 2019-2020 Study

Chapter 4 Contents

This chapter describes the first study in this thesis which took place between October 2019 and February 2020. This study consisted of a pre-test that was designed to collect data from participants when starting at university and a post-test that was designed to collect data after one term of studying at university. We designed the study protocol to allow this survey to be conducted in a lab environment which was monitored by trained research assistants under the supervision of the lead researcher.

We chose three university departments at the University of Essex where participants were expected to have different levels of mathematics backgrounds: participants from the Department of Mathematical Sciences were expected to have high levels of mathematics, with all having studied post-16 mathematics; participants from the Department of Psychology were expected to have a range of mathematical abilities with some having studied post-16 mathematics; participants from the Essex Pathways Department were expected to have generally lower levels of mathematical abilities, with very few having studied post-16 mathematics. However, all departments were common in that they taught a quantitative module in the first term.

4.1 Methodology

The study was approved by the ethics committee of the University of Essex and was conducted in accordance with the ethical principles formulated in the *Declaration of Helsinki* (World Medical Association, 2013). Participants gave informed consent and were not reimbursed for their participation, however they were given the opportunity to request feedback about their performance in the study.

4.1.1 Bespoke Numeracy and Statistics Test

We created a bespoke set of questions that was intended to assess performance accuracy in the quantitative skills necessary for a broad range of degree schemes at university. We required a test that aligned to a specific set of criteria.

Firstly, the test had to assess quantitative performance specific to the mathematical demands of university degree courses. Whilst we have shown that degree courses differ in their needs and uses of mathematics skills (Section 3.5.2), most degrees require a minimum of a pass grade in GCSE Mathematics or equivalent (Hodgen et al., 2014). As such, the questions needed to be pitched at an appropriate level of difficulty and assessed content which a learner who has passed GCSE Mathematics could access.

Secondly, we primarily intended to assess differences between participants with and participants without a post-16 mathematics qualification. As such, we needed questions which varied in their level of difficulty in order to ascertain these differences whilst ensuring that content remained aligned with the above-mentioned criteria. We chose to vary the difficulty by having a number of questions which all participants would be expected to answer correctly, and a number of questions which only participants who had studied post-16 mathematics would be expected to answer correctly. Instead of determining these ability differences by assessing whether an individual had obtained specific post-16 mathematics knowledge, such as hypothesis testing or calculus, we chose to impose differences in the way in which a participant needed to answer the question which aligned with the distinction between a mathematical *exercise* and a mathematical *problem* in Sangwin et al. (2012). This involved thinking about features such as the way that information needed to be processed or complexity in the method that was required to obtain a solution. Low-ability questions generally had a solution that could be obtained with a relatively simple thought process by using information given in the question in an obvious way. On the other hand, high-ability questions needed more consideration over how the information in the question needed to be used which was usually subsequently followed by multiple steps to the required thought process. Additionally, high-ability questions had a variety of feasible approaches, although not all approaches might be successful. This meant that high-ability questions had more areas where a participant could make errors, which we hypothesised would be problematic within individuals without a post-16 mathematics qualification. For example, such individuals could be less likely to implement a clear and structured thought process when answering questions due to lower levels of confidence.

Lastly, we chose a set of quantitative skills that the questions should assess. This is partly influenced by existing quantitative performance tests such as (Greer & Semrau, 1984), however it also aligns with the quantitative needs of first-year university degree courses (Section 3.5.2; Hodgen et al., 2014). We were also led by evidence from teachers and employers which highlighted particular mathematics skills such as mental arithmetic, calculations, estimations, converting between units of measure and interpreting quantitative data as being important (CBI, 2010; Rushton & Wilson, 2014). We chose to focus on two facets of quantitative skills: numeracy and statistics. We interpreted *numeracy* as, “Confidence with the handling of numbers, general mathematical awareness and its application in practical contexts” (CBI, 2010), whilst we chose to interpret *statistics* specifically in this context as *the ability to make calculations and inferences from data* which partially aligns with the aims and intentions of the Large Data Set outlined by Ofqual (Ofqual, 2015). For the numeracy test, we desired questions which aligned to four chosen skill areas:

Calculation	–	using given information to accurately perform arithmetic calculations.
Conversion	–	accurately converting numerical values into another form such as fractions to decimals or converting between units of measurement.
Estimation	–	using rounding or numerical judgments to perform approximate calculations.
Algebra	–	working with unknown quantities in expressions or equations.

For the statistics test, we desired questions which aligned to three chosen skills areas:

Estimation	–	using rounding or statistical judgments to make conclusions about given information or data.
Calculation	–	using given data or information to accurately perform statistical calculations.
Statistical reasoning	–	making interpretations or performing deductions from given information or data.

These skill areas are based loosely on the components of mathematical thinking used in the test administered by Greer & Semrau (1984) as well as some of the numerical and statistical skills shortages detected among undergraduate students in Higher Education (Tariq, 2002).

Since we could not find an established performance instrument which adequately satisfied the specific needs of our study, we elected to design our own set of questions to fit these criteria. In addition, in order to test baseline ability, we elected to design questions which did not require a calculator and, since the questions were multiple-choice, we designed the incorrect answers as distractors according to expected misconceptions or mistakes which a participant may make when attempting the question.

Whilst we did not directly use the 32-item test administered by Greer & Semrau (1984) since it did not satisfy all of our study aims, we did use some of the question types to ensure that our test aligned with established assessment tools that have been used in existing research. This meant that some questions in our test closely aligned with the questions from Greer & Semrau (1984). For instance, the authors instructed participants to perform numerical calculations in their question 4 to calculate each of $\sqrt{0.09}$, 0.02×0.12 and $40 \div 0.8$, whereas we altered these questions to instruct our participants to find each of $\sqrt{0.04}$ (numeracy question 17), 0.03×0.4 (numeracy question 16) and $60 \div 0.15$ (numeracy question 15), respectively. Another example was that the authors used the set of numbers 0.25, 0.0099, $2/3$, $1/50$ and $3/200$ in their question 8 and instructed participants to arrange these in size order starting with the smallest, whereas we gave the numbers 0.001, $1/10$, 10^{-4} and 1% of 1 and instructed our participants to find the smallest value (numeracy question 12). A total of nine questions across our numeracy and statistics tests were similar to questions in the test by Greer & Semrau (1984).

After conducting the study, we elected to perform a post-hoc selection method to obtain eight numeracy and eight statistics questions at the pre- and post-test which would be used for analysis. We therefore imposed the criteria that we required at least one question from each of the skill areas and that there would be an equal number of questions aligning to the two levels of difficulty: Level 1 (questions aimed at participants who had studied mathematics up until GCSE) and Level 2 (questions aimed at participants who had studied post-16 mathematics).

Since our selection method was post-hoc, we based it on statistics calculated from the performance data of each group. We acknowledge Classical Test Theory (CTT; Spearman, 1904; Novick, 1966; Traub, 1997) and Item Response Theory (IRT; Lord, 1952; Lord & Novick, 1968) when developing our approach. Whilst CRT tends to rely on simple descriptive statistics, IRT is a model-based approach that aims to evaluate test performance based on how individuals answer each question. Specifically, IRT takes into account discrimination between individuals with different ability levels and guessing effects by fitting an Item Characteristic Curve that is based on the probability that individuals with given ability levels are able to provide the correct answer to each test item. Despite IRT offering a greater level of complexity, we opted to use a selection method that was based on descriptive statistics as well as giving reasoning for accepting or rejecting items based on adherence item subscales.

We removed questions N20 and S11, S12, S13, S14, S15 from analysis on the basis that these questions were asked at the post-test only. We also removed question S9 from analysis since an incorrect version of this question was inadvertently shown to one group of participants that could have had two possible correct answers. We then formed two groups of participants consisting of those with and those without a post-16 mathematics qualification and analysed the mean performance accuracy per question for each group at the pre-test and the post-test Table 4.1 We then grouped the numeracy questions into four groups and the statistics questions into three groups according to the skills which the question was designed to assess. In the event that a question was not uniquely defined by one skill group, we allowed this question to appear multiple times in each of its respective skill groups.

After rejecting six of the potential 15 statistics questions for analysis, we only needed to remove one additional question. We chose to reject S6 on the basis that this question had the highest proportion of participants obtaining the correct answer whilst also exhibiting the smallest amount of variation between the pre-test and the post-test as well as between groups of participants with and without a post-16 mathematics qualification. Removing this question allowed us to obtain a set of statistics questions which aligned to our criteria.

To select numeracy questions we firstly aimed to reject one question from each group which had the highest accuracy between all groups of participants (i.e., with and without post-16 mathematics at both the pre-test and the post-test). This was because we aimed to find evidence of differences between the groups of participants with and without a post-16 mathematics qualification and so questions which showed a similarly high performance accuracy across all participants did not fulfil this purpose. We achieved this by using a threshold test with 10%

Table 4.1 | The mean accuracy scores for the questions from the 2019-2020 Study.

Question	Skill(s)	Difficulty	Pre-test Accuracy		Post-test Accuracy	
			With Post-16 Maths	Without Post-16 Maths	With Post-16 Maths	Without Post-16 Maths
N1	Calculation	Level 1	87%	84%	85%	85%
N2	Calculation	Level 2	42%	24%	38%	39%
N3	Algebra	Level 1	77%	51%	68%	70%
N4	Conversion	Level 1	60%	55%	68%	51%
N5	Calculation	Level 1	75%	28%	52%	54%
N6	Calculation	Level 1	96%	84%	88%	91%
N7	Conversion	Level 2	36%	17%	32%	33%
N8	Calculation	Level 1	86%	68%	72%	85%
N9	Calculation	Level 1	80%	60%	72%	67%
N10	Calculation	Level 1	93%	84%	90%	93%
N11	Conversion	Level 1	84%	63%	72%	85%
N12	Conversion	Level 1	86%	62%	72%	79%
N13	Calculation	Level 1	94%	83%	98%	88%
N14	Calculation	Level 1	92%	78%	88%	87%
N15	Estimation	Level 2	68%	48%	62%	58%
N16	Estimation	Level 2	55%	39%	52%	61%
N17	Algebra	Level 2	53%	31%	50%	43%
N18	Algebra	Level 1	93%	83%	82%	90%
N19	Algebra	Level 1	95%	86%	92%	90%
N20	Calculation	Level 2	–	–	38%	31%
S1	Calculation	Level 2	71%	64%	72%	67%
S2	Estimation	Level 2	64%	72%	68%	70%
S3	Estimation	Level 1	40%	35%	52%	46%
S4	Statistical Reasoning	Level 1	69%	68%	72%	69%
S5	Estimation	Level 2	60%	62%	45%	63%
S6	Calculation	Level 1	92%	90%	90%	93%
S7	Statistical Reasoning	Level 1	55%	46%	62%	48%
S8	Calculation	Level 1	95%	91%	90%	87%
S9	Statistical Reasoning	Level 2	54%	43%	92%	91%
S10	Statistical Reasoning	Level 2	60%	55%	48%	63%
S11	Estimation	Level 2	–	–	42%	30%
S12	Statistical Reasoning	Level 1	–	–	82%	78%
S13	Calculation	Level 1	–	–	20%	13%
S14	Statistical Reasoning	Level 2	–	–	62%	64%
S15	Statistical Reasoning	Level 2	–	–	90%	93%

For convenience, questions are numbered here to correspond with the order given in Chapter A. Numeracy and statistics questions are labelled with the prefix *N* and *S*, respectively. The respective difficulty of each question is either *Level 1* being an easier standard which all participants should be able to access, or *Level 2* being a harder standard which is more accessible to participants with a post-16 mathematics qualification. The accuracy percentages were calculated as the mean number of participants in each group that got the correct answer on the question in the 2019-2020 Study.

Table 4.2 | The selected numeracy and statistics questions for the 2019-2020 Study.

Question	Difficulty	Skills					Pre-test Accuracy		Post-test Accuracy	
		Alg	Con	Calc	Esti	S R	With Post-16 Maths	Without Post-16 Maths	With Post-16 Maths	Without Post-16 Maths
N3	Level 1	■					77%	51%	68%	70%
N5	Level 1			■			75%	28%	52%	54%
N7	Level 2		■				36%	17%	32%	33%
N8	Level 1			■			86%	68%	72%	85%
N11	Level 1		■				84%	63%	72%	85%
N15	Level 2				■		68%	48%	62%	58%
N16	Level 2				■		55%	39%	52%	61%
N17	Level 2	■					53%	31%	50%	43%
S1	Level 2			■			71%	64%	72%	67%
S2	Level 2				■		64%	72%	68%	70%
S3	Level 1				■		40%	35%	52%	46%
S4	Level 1					■	69%	68%	72%	69%
S5	Level 2				■		60%	62%	45%	63%
S7	Level 1					■	55%	46%	62%	48%
S8	Level 1			■			95%	91%	90%	87%
S10	Level 2					■	60%	55%	48%	63%

The numeracy and statistics skills have been abbreviated to *Alg* = Algebra, *Con* = Conversion, *Calc* = Calculation, *Esti* = Estimation, *S R* = Statistical Reasoning. A shaded cell indicates the skills which correspond to each question. Numeracy and statistics questions are labelled with the prefix *N* and *S*, respectively. The respective difficulty of each question is either *Level 1* being an easier standard which all participants should be able to access, or *Level 2* being a harder standard which is more accessible to participants with a post-16 mathematics qualification. The accuracy percentages were calculated as the mean number of participants in each group that got the correct answer on the question in the 2019-2020 Study.

decrements to remove questions where high proportions of participants had answered the questions correctly, thus failing to show the differences that we were interested in investigating. We started with a threshold of 90% (i.e., more than 90% of participants with and without a post-16 mathematics qualification answered the question correctly at the pre-test and the post-test) and rejected the questions in each skill group where all accuracy scores were above this threshold. If we failed to reject any questions in the group, we changed the threshold to 80% and then 70% if we still failed to reject any questions in the skill group. In the event that more than one question in the group was rejected by our threshold test, we would reject all the associated questions, providing that at least one question would still remain in the group. There were no instances where we rejected all questions in the group using this threshold test. We did not use a threshold below 70% in our first iteration since we believed that this would show the required differences that we were interested in investigating. This threshold test produced 13 potential numeracy questions consisting of eight questions at Level 1 difficult and five questions at Level 2 difficulty.

We then focused on ensuring that the skill areas had an even distribution of questions and so focused on the skill areas of calculation and conversion since these had more questions than the other group. We aimed to remove three questions from the calculation group and two questions from the conversion group since this would then give two questions from each of the four skill areas. We achieved this by removing questions which had the smallest difference in mean performance accuracy between the group of participants with and the group of participants without a post-16 mathematics qualification. This left us with a set of numeracy questions which aligned with our original criteria.

The eight numeracy questions and eight statistics questions which were used for analysis are shown in Table 4.2.

4.1.2 Study Participants

The experiment recruited 238 undergraduate students from Essex Pathways Department (foundation year), the Department of Mathematical Sciences (first year) and the Department of Psychology (first year) at the University of Essex. These departments were selected on the basis that they would all teach a quantitative module in the first term, however the amount of prior mathematics and statistics knowledge was expected to vary between each department: participants from Essex Pathways Department were expected to have limited knowledge; participants from the Department of Mathematics were expected to have a high amount of knowledge; participants from the Department of Psychology were expected to have some knowledge. All participants were recruited through voluntary lab sessions which were scheduled on their university timetables.

At the post-test, participants were again recruited through lab sessions which were scheduled on their timetables. To limit the possibility of a participant completing the post-test without having also completed the pre-test, the lead researcher instructed those who had not completed the survey at the pre-test not to take the survey the start of each lab. 106 participants successfully completed the post-test. Some participants could not be confidently matched between the pre-test and the post-test due to obvious differences in responses to the demographic questions between the pre-test and post-test. In addition, the timetable invited the same group to the post-test, irrespective of whether they had participated in the pre-test. This meant that some participants did not follow the lead researcher's instruction and thus completed the post-test without also completing the pre-test. After exclusions, we used 72 participants for analysis who had completed both the pre-test and the post-test.

Since Essex Pathways Department had poor recruitment for the pre-test we decided not to follow-up recruitment from this department for the post-test on the reasoning that there was not a substantial sample for the pre-test and the expected attrition rate between the pre- and post-test would make it hard to recruit the same participants for analysis. The demographic characteristics of the study population at the pre-test, post-test and the pre-/post-test are shown in Table 4.3.

We also detail the particular mathematics qualifications detailed by participants who stated that they studied mathematics between the ages of 16-18 in Table 4.4.

Table 4.3 | The demographic characteristics of the study population.

	Degree Course	Gender				Age	Post-16 Study		Post-16 Maths		Foundation Year	
		Female	Male	Other	Total		UK	Non-UK	With	Without	Yes	No
Pre-test	Psychology	133	55	1	189	18-21	145	44	81	108	23	166
	Mathematics	13	24	0	37	18-21	26	11	33	4	2	35
	Pathways	6	6	0	12	18-21	9	3	4	8	10	2
	Total	**152**	**85**	**1**	**238**	**18-21**	**180**	**58**	**118**	**120**	**35**	**203**
Post-test	Psychology	62	26	0	88	18-21	61	27	41	47	17	71
	Mathematics	6	12	0	18	18-21	14	4	18	0	2	16
	Pathways	–	–	–	–	–	–	–	–	–	–	–
	Total	**68**	**38**	**0**	**106**	**18-21**	**75**	**31**	**59**	**47**	**19**	**87**
Pre-/post-test	Psychology	49	19	0	68	18-21	45	23	30	38	7	61
	Mathematics	1	3	0	4	18-21	4	0	4	0	0	4
	Pathways	–	–	–	–	–	–	–	–	–	–	–
	Total	**50**	**22**	**0**	**72**	**18-21**	**49**	**23**	**34**	**38**	**7**	**65**

Psychology = Department of Psychology, *Mathematics* = Department of Mathematical Sciences, *Pathways* = Essex Pathways Department. We asked participants to indicate their age from three broad categories: 18-21, 22-25, 26+. As such, the age column in the table above indicates the modal age category.

Table 4.4 | Frequencies of participants who had studied post-16 mathematics qualifications.

Post-16 Mathematics Qualification	Pre-test	Post-test	Pre-/post-test
Core Mathematics	31	5	5
AS-Level Mathematics	28	12	7
A-Level Mathematics	47	22	8
AS-Level Further Mathematics	6	4	1
A-Level Further Mathematics	7	3	0
AS-Level Statistics	12	3	2
A-Level Statistics	12	7	3
IB Mathematics Studies SL	2	2	1
IB Mathematics SL	0	0	0
IB Mathematics HL	1	1	0
IB Further Mathematics HL	0	0	0
Other UK Qualification	0	0	0
Non-UK Qualification	35	22	17

IB = International Baccalaureate, *SL* = Standard Level, *HL* = Higher Level. Note that this list does not represent unique numbers of participants since it was possible for participants to have taken more than one post-16 mathematics qualification.

4.1.3 Study Materials

Numeracy test

Participants were given a set of 19 numeracy questions at the pre-test and 20 numeracy questions at the post-test. For each question, participants were given a set of four multiple-choice options with only one option being correct. The question order and the order of the multiple-choice options were randomised. The questions covered four skill areas: calculation; conversions; estimation; algebra. In order to ensure that all participants could reasonably be expected to attempt all items, questions were designed to utilise knowledge from topic areas up to and including GCSE Mathematics. We wrote the numeracy questions with the intention that they should vary in difficulty and thus expected the internal consistency to be low. To control for this and the fact there were not the same number of numeracy questions at the pre- and post-test, we used a selection method (see Section 4.1.1) to select eight numeracy questions to use for analysis: four questions which all participants would be expected to answer correctly; four questions which participants with post-16 mathematics were more likely to answer correctly. Participants were instructed not to use a calculator and advised to spend approximately one minute answering each question prior to starting the numeracy test. Plain paper was provided on their desks for any rough working and participants were provided with pens on request. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the eight items for overall scores.

Statistics test

As in the numeracy test, participants were given a set of 10 statistics questions at the pre-test and 15 statistics questions at the post-test. These questions were a similar difficulty to the numeracy test and also did not ask about specialist terminology or concepts so that a participant with a pass grade in GCSE Mathematics should reasonably be expected to answer. As with the numeracy questions, we used a selection method (see Section 4.1.1) to select eight statistics questions to use for analysis: four questions which all participants would be expected to answer correctly; four questions which participants with post-16 mathematics were more likely to answer correctly. For each question, participants were given a set of multiple-choice options with only one option being correct. The question order and the order of the multiple-choice options were randomised. The questions covered three skill areas: calculation; estimation; statistical reasoning. To ensure consistency with the procedure for the numeracy questions, participants were given the same instructions and advice regarding not using a calculator and expected time per question and given pen and paper materials for rough working. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the eight items for overall scores.

Confidence judgments

After each numeracy and statistics question, participants were asked, “How confident are you in your answer?" and had to rate their confidence according to a 11-point Likert scale (0 = *not at all confident*, 10 = *very confident*). An overall confidence score for both the numeracy and statistics questions was calculated by averaging all confidence ratings. Additional accuracy scores for the numeracy and statistics questions were calculated by first determining the thresholds for each participant as *high confidence* (confidence rating above the upper quartile of the confidence judgments) and *low confidence* (confidence rating below the lower quartile of the confidence judgments). Each question was then coded as *accurate* (numeric value of 1: either high confidence and question correct, or low confidence and question incorrect) or *inaccurate* (numeric value of 0: either low confidence and question correct, or high confidence and question incorrect). These scores were averaged to obtain overall accuracy scores for the statistics questions and for the numeracy questions which corresponded to the proportion of accurate judgments for each test. Figure 4.1 shows the confidence scale which was asked after each of the numeracy and statistics questions.

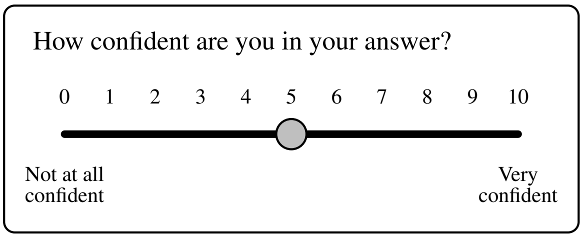


Figure 4.1 | The confidence scale which was asked after each of the numeracy and statistics questions.

Personality traits

Participants' personality traits were assessed with the Big Five Inventory 2 (BFI-2, Soto & John, 2017a). The questionnaire consisted of 60 short, descriptive phrases which participants were asked to rate their agreement with on a five-point Likert scale (1 = *strongly disagree*, 5= *strongly agree*). To prevent boredom or fatigue, we split the personality questionnaire such that the first 30 items were administered immediately after the numeracy test and the second 30 items were administered immediately after the statistics test. Items completed the sentence stem "I am someone who..." and measured each of the five personality traits using 12 items per trait:

- **Openness** e.g., is curious about many things.
- **Conscientiousness** e.g., is systematic, likes keeping things in order.
- **Extraversion** e.g., is outgoing, sociable.
- **Agreeableness** e.g., is compassionate, has a soft heart.
- **Neuroticism** e.g., worries a lot.

Scores for each personality trait were calculated by firstly reverse coding specific items as per the instructions by Soto & John (2017a) and then taking the mean average of the 12 ratings for each personality trait. This obtained five values corresponding to each of the five personality traits which ranged between 1 (low in this trait) and 5 (high in this trait). Table 4.5 shows that our study had similar reliability to the US version of Soto & John (2017a).

Table 4.5 | Comparing the reliability (Cronbach's alpha) of the BFI-2 personality instrument for our study and the US version from Soto & John (2017a).

Trait	Our Study	US Version
Openness	$\alpha = 0.807$	$\alpha = 0.82$
Conscientiousness	$\alpha = 0.838$	$\alpha = 0.84$
Extraversion	$\alpha = 0.871$	$\alpha = 0.87$
Agreeableness	$\alpha = 0.751$	$\alpha = 0.82$
Neuroticism	$\alpha = 0.875$	$\alpha = 0.82$

Numeracy ability and preference

Since our numeracy and statistics test was a bespoke instrument designed for measuring performance accuracy, we opted to validate our instrument using the Subjective Numeracy Scale (SNS, Fagerlin et al., 2007). Although the SNS is a subjective measure of quantitative ability, the SNS has been proven to correlate highly with objective measures of numerical performance (Zikmund-Fisher et al., 2007). The eight-item questionnaire contains two subscales: four items where respondents are asked to assess their numerical ability in different contexts (e.g., *How good are you at working with percentages?*) on a six-point Likert scale (1 = *not at all good*, 6 = *extremely good*); four items where respondents are asked to state their preference for the presentation of numerical and probabilistic information (e.g., *When people tell you that the chance of something happening, do you prefer that they use words ("it rarely happens") or numbers (there is a 1% chance)?*) on a six-point Likert scale (e.g., 1 = *always prefer words*, 6 = *always prefer numbers*). An overall SNS score is obtained by firstly reverse coding specific items and then taking the mean average of all ratings which gives an SNS value between 1 (low numerate) and 6 (highly numerate). An ability and preference score is also obtained by averaging the four items corresponding to each subscale. The internal consistency (Cronbach's alpha) for the SNS in our study was $\alpha = 0.758$ and $\alpha = 0.775$ at the pre-test and post-test respectively, which shares similar reliability with the authors' reported $\alpha = 0.807$.

Mathematics anxiety

Whilst the literature reports many instruments that measure mathematics anxiety, we chose to use the Adult Everyday Mathematics Anxiety Scale (AEMAS, Rolison et al., 2016). We chose this scale for the reported high internal consistency ($\alpha = 0.93$) combined with the low number of items allowing it to be administered in a short amount of time, as well as its suitability for British adults. Participants were given 13 scenarios involving everyday mathematical tasks (e.g., *Figuring out how much a shirt will cost if it is 25% off*) and asked to rate how anxious they would feel during the event specified on a five-point Likert scale (1 = *low anxiety*, 2 = *some anxiety*, 3 = *moderate anxiety*, 4 = *quite a bit of anxiety*, 5 = *high anxiety*). A mathematics anxiety score for each participant was obtained by calculating the mean average of all 13 items. The internal consistency (Cronbach's alpha) of this instrument in our study was $\alpha = 0.909$ and $\alpha = 0.905$ at the pre-test and the post-test respectively which is of a similar level to the reliability reported by the authors.

4.1.4 Study Procedure

The pre-test was open in the Autumn term from 8th October 2019 to 5th November 2019 in order to ensure that participants would only be exposed to a maximum of five weeks of university teaching. The post-test was open in the Spring term from 16th January 2020 to 7th February 2020 which equates to the same amount of term time as the pre-test. A total of nine 50-minute lab sessions were timetabled at the pre-test and six lab sessions were timetabled at the post-test. Due to the lab capacity, participants could only attend the lab in which they were timetabled for.

Each lab session was conducted by the lead researcher and two research assistants who monitored the participants during the survey. Prior to the start of the lab, a consent form, participant information sheet and a single sheet of plain A4 paper was placed in front of the computers. The lab was arranged in rows where all computers faced the same direction. As such, these documents were placed in front of alternate computers to limit the possibility of participants being able to easily view each other's computer screen. When participants arrived in the lab, they were instructed to sit at a computer where these documents had been placed and told to log on to the computer using their university intranet credentials and open a web browser.

The experiment started five minutes after the scheduled start time to allow any latecomers to enter the lab without causing disturbance to other participants. A member of staff from the participants' department commenced by giving a short introduction about the study. The lead researcher then gave information about the purposes of the survey and invited participants to read the participant information sheet and fill in their details on the consent form. During this time, participants were invited to ask any questions and were also given the opportunity to withdraw from the study if they opted not to participate.

The survey was programmed using the online survey platform Qualtrics which was accessed via a TinyURL web address. Once participants had adequate time to fill in the consent form, the lead researcher displayed the TinyURL on the digital screens that were positioned around the room. Each of the research assistants also had hard copies should any participants find it difficult to read from the screens. Participants were instructed to type this TinyURL into their web browsers and commence the survey. The lead researcher and the research assistants circulated the room to make sure that all participants had successfully accessed the survey.

The first page of the survey requested participants to enter the unique participant number which was given to them on the consent form which they had just signed. On completion of the experiment, participants were shown a screen which instructed them to raise their hands and wait for a research assistant to come to them. The research assistant would check to ensure that all details on the consent form had been successfully completed and then instruct the participant to log off their computer and leave the lab quietly to minimise disturbance to other participants. The consent form was collected and the plain paper was disposed of.

After each lab session, the lead researcher would create a secure digital record of the participant numbers corresponding to the name or registration number which each participant had given on the consent form. This information was used to match participants' responses between the pre-test and the post-test and was kept separate from the data analysis.

4.1.5 The Course of the Experiment

The experiment started with a short demographic questionnaire followed by the numeracy test, the first 30 items of the Big Five Inventory (BFI-2), the statistics test, the next 30 items of the Big Five Inventory (BFI-2), the Subjective Numeracy Scale, the Adult Everyday Mathematics Anxiety Scale (AEMAS). After each of the questions in the numeracy and statistics test, participants were asked to rate their confidence in the correctness of their answer in the previous question. Figure 4.2 displays the course of the experiment for the pre-test and the post-test. The BFI-2 was only administered at the pre-test since personality traits are reported to remain relatively stable over time, particularly for the time period between the pre-test and the post-test (Bleidorn et al., 2019; McCrae & Costa, 1995).

4.1.6 Sample Size Calculations

Given that 72 participants completed both the pre-test and the post-test, with 34 participants with and 38 participants without a post-16 mathematics qualification, we investigated whether the sample size possessed enough statistical power to assess differences between the groups. Considering two independent sample t-tests for 13 primary hypotheses which were Bonferroni corrected to give a significance level of $\frac{5\%}{13} = 0.38\%$ and using a standard deviation of 0.125 and a desired statistical power of 80%, we found that the sample size was powered enough to detect differences in accuracy as small as 11.7%.

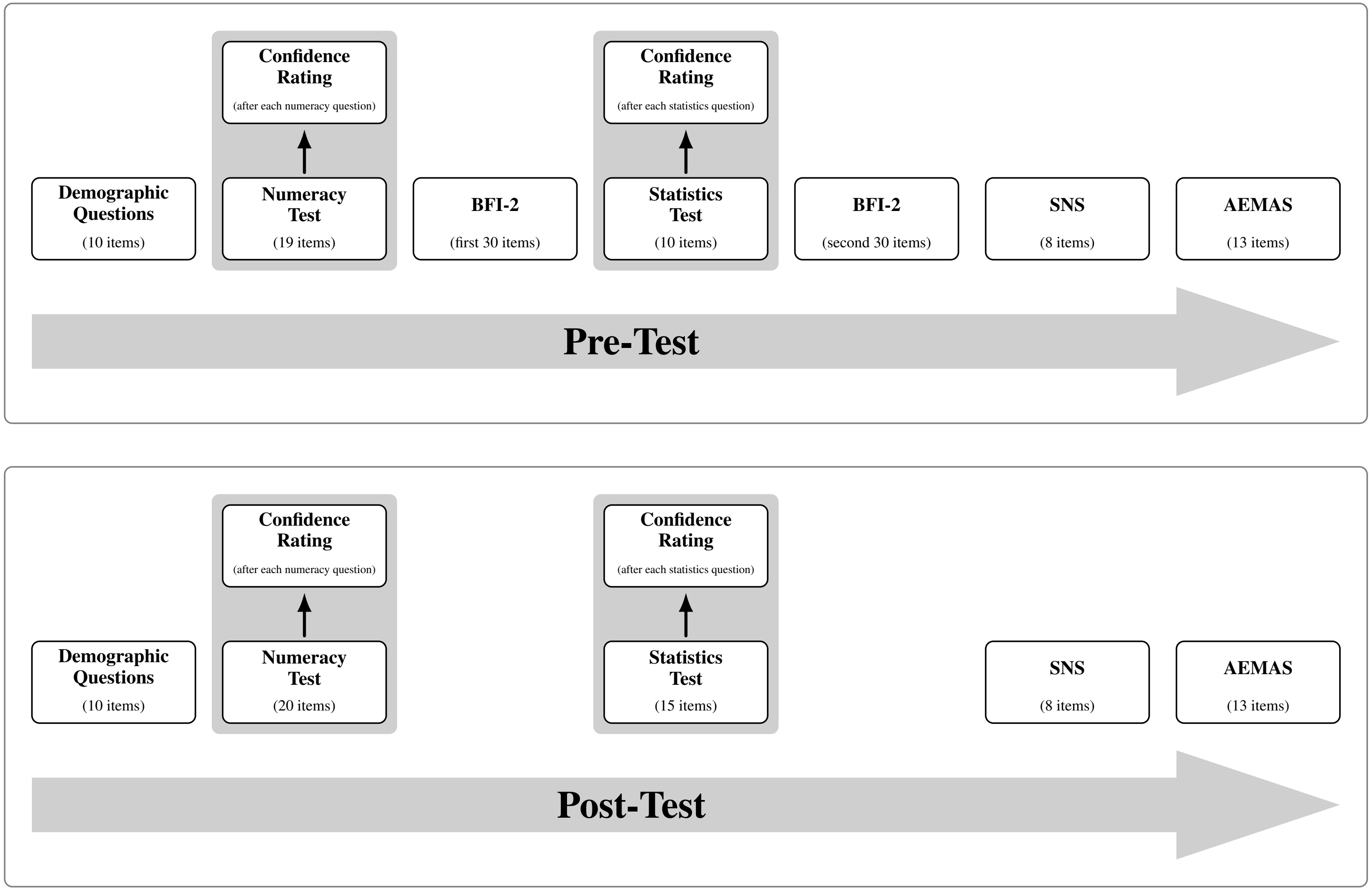


Figure 4.2 | The course of the experiment at the pre-test and the post-test. *BFI-2* = Big Five Inventory 2; *SNS* = Subjective Numeracy Scale; *AEMAS* = Adult Everyday Mathematics Anxiety Scale.

4.1.7 Statistical Analysis

Although this study was not pre-registered, the main analysis followed the same structure as given in Chapter 6 which was listed for the 13 hypotheses. We also formed path analysis models and explored additional relationships as exploratory analysis.

We tested for the assumption of normality in the data using a Shapiro-Wilk test on the groups of participants with and without a post-16 mathematics qualification. Most of the variables which were to be used in the primary analysis were found not to be normally distributed which we further verified using visual inspection of their histograms and measuring skewness and kurtosis (Table 4.6). Whilst a statistical transformation of the data may have allowed us to use parametric techniques, we instead chose to proceed with a more robust approach of non-parametric analysis. As such, the main analysis consisted of Wilcoxon signed-rank tests to determine differences between groups and Spearman rank-order correlation tests to determine correlations between variables. For the Wilcoxon signed-rank tests we report the test statistic W, the Bonferroni-adjusted p-value, the 95% confidence interval based on the scale of individuals, and the Cohen's d effect size. For the Spearman rank-order correlation tests we report the test statistic S, the Bonferroni-adjusted p-value, and the correlation coefficient ρ.

The exploratory analysis consisted of path analysis models using a combination of demographic and observed scores to predict the numeracy and statistics scores at each of the pre-test, post-test and pre-/post-test. Each model was subjected to goodness-of-fit statistics to assess how well the model fit the data, of which we primarily used the Root Mean Square Error of Approximation (RMSEA) and the χ^2 goodness-of-fit indices. We looked for a RMSEA value of less than 0.08 in order to be considered a good fit for the data and, likewise, a non-significant χ^2 value suggested evidence in favour of the null hypothesis that the model fits the data (Hu & Bentler, 1999). To control for effects of sample size on the RMSEA and χ^2 values, we also used additional fit indices of Standardised Root Mean Square Residual (SRMR), Tucker-Lewis Index (TLI) and the Comparative Fit Index (CFI), of which SRMR < 0.08, TLI > 0.95 and CFI > 0.90 were considered as optimal thresholds to indicate that the model fits the data (Hu & Bentler, 1999). To ensure good model fit, we started with a hypothesised model including all variables and used

Table 4.6 | Testing the normality assumptions for the variables performance accuracy, retrospective confidence judgments and mathematics anxiety for the groups with and without a post-16 mathematics qualification at the pre- and post-test.

		Post-16 Maths	*W*	*p*-value	Skewness	Kurtosis
Pre-test	Performance accuracy	With	0.958	<0.001	-0.308	2.221
		Without	0.969	<0.01	0.409	3.283
	Confidence	With	0.934	<0.001	-0.834	3.149
		Without	0.99	0.5696	-0.214	2.682
	Maths Anxiety	With	0.951	<0.001	0.582	2.647
		Without	0.978	0.0508	0.386	2.886
Post-test	Performance accuracy	With	0.951	0.0181	-0.641	2.970
		Without	0.953	0.0507	0.406	2.251
	Confidence	With	0.938	<0.01	-0.386	1.946
		Without	0.96	0.1071	-0.557	2.968
	Maths Anxiety	With	0.946	0.0105	0.803	3.280
		Without	0.978	0.4937	0.167	2.970

a backwards selection method to remove non-significant variables until we achieved a model with goodness-of-fit indices within the desired ranges.

The data was analysed using the R language and environment for statistical computing and graphics version 4.3.2 (R Core Team, 2023) and the integrated environment R Studio version 2023.12.1+402. We used the R packages: lavaan (Rosseel, 2012); lavaanPlot (Lishinski, 2024); effsize (Torchiano, 2020); moments (Komsta & Novomestky, 2022).

4.2 Results

For the purposes of brevity and clarity we will refer to Group 1 and Group 2 as:

Group 1: Participants who had studied a post-16 mathematics qualification.

Group 2: Participants who had not studied a post-16 mathematics qualification.

4.2.1 Main Analysis

Hypothesis 1: Performance accuracy in numeracy and statistics tests

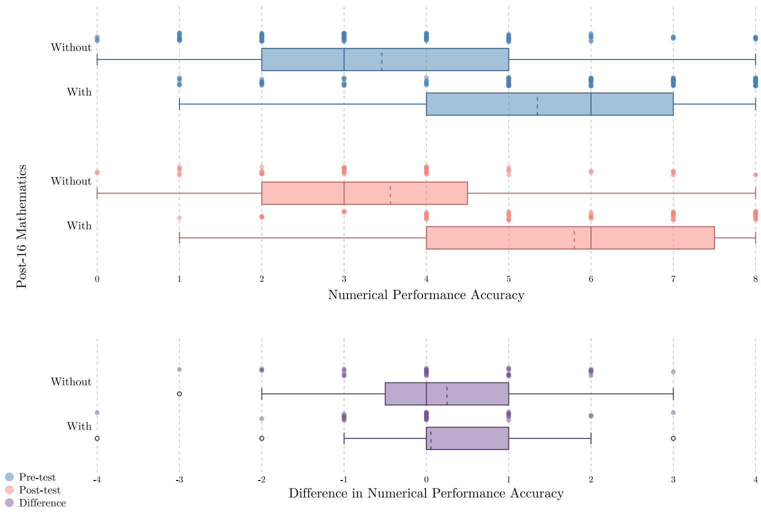
Primary Analysis

Group 1 exhibited higher performance accuracy at the pre-test than Group 2 (Wilcoxon-test: $W = 9866$, $p < 0.001$, $95\%CI = [2.000, 3.000]$, $d = 0.701$). This difference was still detected at the post-test (Wilcoxon-test: $W = 2024$, $p < 0.01$, $95\%CI = [1.000, 4.000]$, $d = 0.798$). When comparing differences in performance accuracy scores between the pre- and the post-test, no significant differences were found between these groups (Wilcoxon-test: $W = 637$, $p = 0.7504$, $95\%CI = [-0.500, 0.500]$, $d = -0.114$).

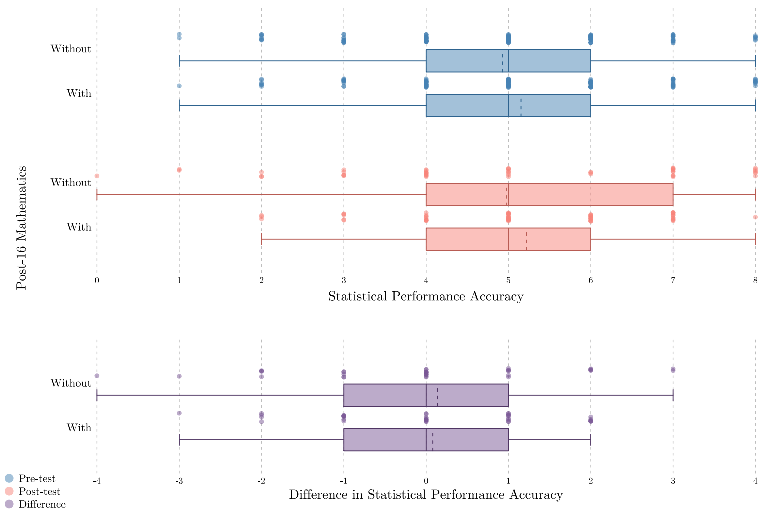
Secondary Analysis

When analysing differences for only the numeracy test, we found that Group 1 still exhibited higher performance accuracy on the numeracy test at the pre-test than Group 2 (Wilcoxon-test: $W = 10\,456$, $p < 0.001$, $95\%CI = [2.000, 3.000]$, $d = 0.921$) and this difference was still detected at the post-test (Wilcoxon-test: $W = 2217.5$, $p < 0.001$, $95\%CI = [2.000, 3.000]$, $d = 1.121$). There was no significant difference in the change of performance accuracy on the numeracy test between the pre- and post-test for either group (Wilcoxon-test: $W = 602.5$, $p = 0.4689$, $95\%CI = [-1.000, 0.000]$, $d = -0.153$).

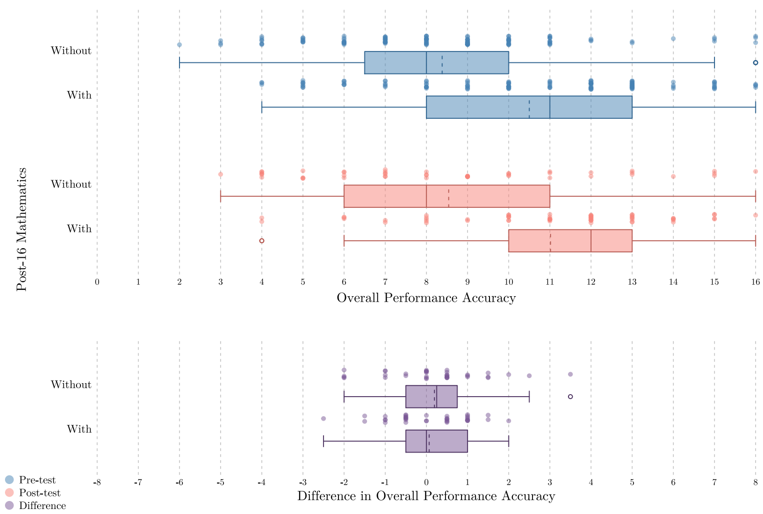
When analysing differences in performance accuracy for only the statistics test, there were no significant differences between the groups at the pre-test (Wilcoxon-test: $W = 76\,035$, $p = 0.3013$, $95\%CI = [0.000, 1.000]$, $d = 0.139$). There were also no significant difference between



(a) Performance accuracy scores on the numeracy tests.



(b) Performance accuracy scores on the statistics tests.



(c) Overall performance accuracy scores.

Figure 4.3 | Boxplots showing the overall performance accuracy scores for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in performance accuracy scores between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

each group at the post-test (Wilcoxon-test: $W = 1492$, $p = 0.631$, $95\%CI = [-1.000, 1.000]$, $d = 0.135$). There was no significant difference in the change of performance accuracy on the statistics test between the pre- and post-test for either group (Wilcoxon-test: $W = 667$, $p = 0.9955$, $95\%CI = [-1.000, 1.000]$, $d = -0.037$).

Hypothesis 2: Retrospective confidence judgments.

Primary Analysis

Group 1 rated themselves as more confident when answering numeracy and statistics items than Group 2 at the pre-test (Wilcoxon-test: $W = 9771.5$, $p < 0.001$, $95\%CI = [0.813, 1.812]$, $d = 0.675$).

There was a significant positive correlation between retrospective confidence ratings and performance accuracy on the numeracy and statistics tests at the pre-test (Spearman rank correlation coefficient: $S = 986\,195$, $p < 0.001$, $\rho = 0.561$).

Secondary Analysis

There was a significant difference between Group 1 and Group 2 when comparing their retrospective confidence ratings on the numeracy and statistics items at the post-test (Wilcoxon-test: $W = 1751.5$, $p = 0.0359$, $95\%CI = [0.062, 1.625]$, $d = 0.457$). We also analysed the differences between the groups for retrospective confidence ratings on the numeracy items and on the statistics items at each of the pre- and post-tests. We found that Group 1 rated themselves as more confident on the numeracy items at the pre-test (Wilcoxon-test: $W = 10\,260$, $p < 0.001$, $95\%CI = [1.250, 2.500]$, $d = 0.841$) and at the post-test (Wilcoxon-test: $W = 1933.5$, $p < 0.01$, $95\%CI = [0.625, 2.250]$, $d = 0.697$). Group 1 also rated themselves as more confidence on the statistics items than Group 2 at the pre-test (Wilcoxon-test: $W = 8683$, $p < 0.01$, $95\%CI = [0.250, 1.125]$, $d = 0.377$) but this difference did not hold at the post-test (Wilcoxon-test: $W = 1501.5$, $p = 0.5943$, $95\%CI = [-0.500, 1.000]$, $d = 0.158$).

There was a significant positive correlation between retrospective confidence ratings and performance accuracy on the numeracy and statistics tests at the post-test (Spearman rank correlation

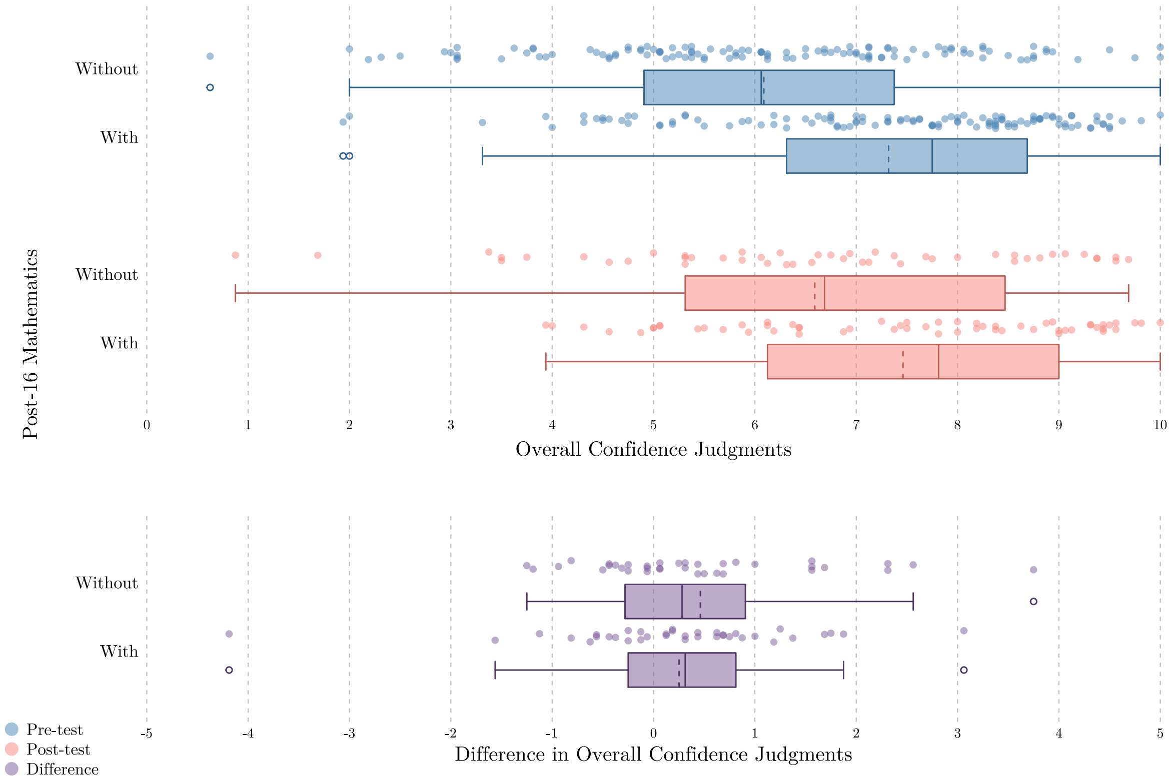


Figure 4.4 | Boxplots showing the overall confidence judgments for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in confidence judgments between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

coefficient: $S = 85\,398$, $p < 0.001$, $\rho = 0.582$).

Hypothesis 3: Mathematics anxiety.

Primary Analysis

Group 1 were found to have lower mathematics anxiety than Group 2 at the pre-test (Wilcoxon-test: $W = 5349.5$, $p = 0.0145$, $95\%CI = [-0.615, -0.154]$, $d = -0.424$).

There was a significant negative correlation between mathematics anxiety and performance accuracy on the numeracy and statistics tests at the pre-test (Spearman rank correlation coefficient: $S = 3\,149\,413$, $p < 0.001$, $\rho = -0.402$).

There was a significant negative correlation between retrospective confidence ratings and mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 3\,415\,758$, $p <$

Figure 4.5 | Scatterplot showing the statistically significant correlation between the performance accuracy scores and the confidence judgments at the pre-test. This plot also shows a simple linear regression model $\hat{y} = 3.28 + 0.94x$, $R^2 = 30.0\%$ which has been added to aid with graphical visualisation.

0.001, $\rho = -0.520$).

Secondary Analysis

There was no significant difference between mathematics anxiety levels for either group at the post-test (Wilcoxon-test: $W = 1105$, $p = 0.0516$, $95\% CI = [-0.615, -0.000]$, $d = -0.308$).

There were still negative correlations between mathematics anxiety and performance accuracy on the numeracy and statistics tests at the post-test (Spearman rank correlation coefficient: $S = 288\,981$, $p < 0.001$, $\rho = -0.415$) as well between retrospective confidence ratings and mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 296\,541$, $p < 0.001$, $\rho = -0.453$).

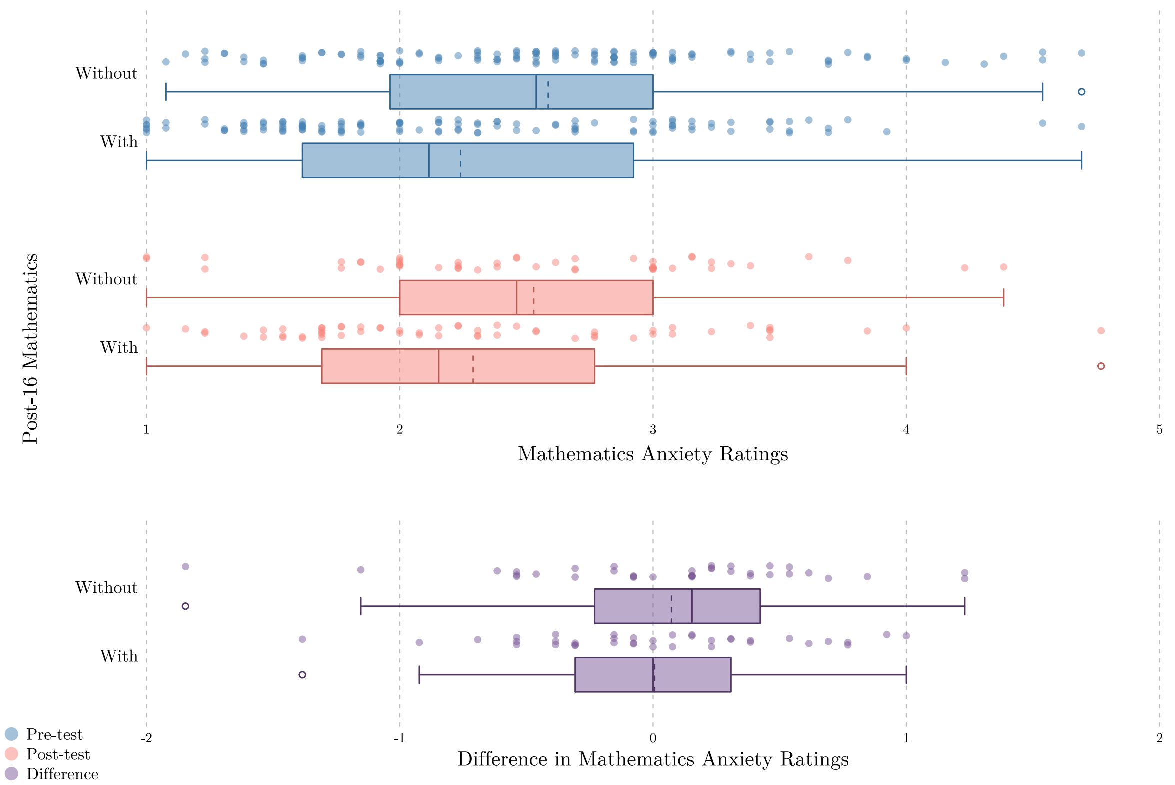


Figure 4.6 | Boxplots showing the mathematics anxiety ratings for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in mathematics anxiety ratings between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

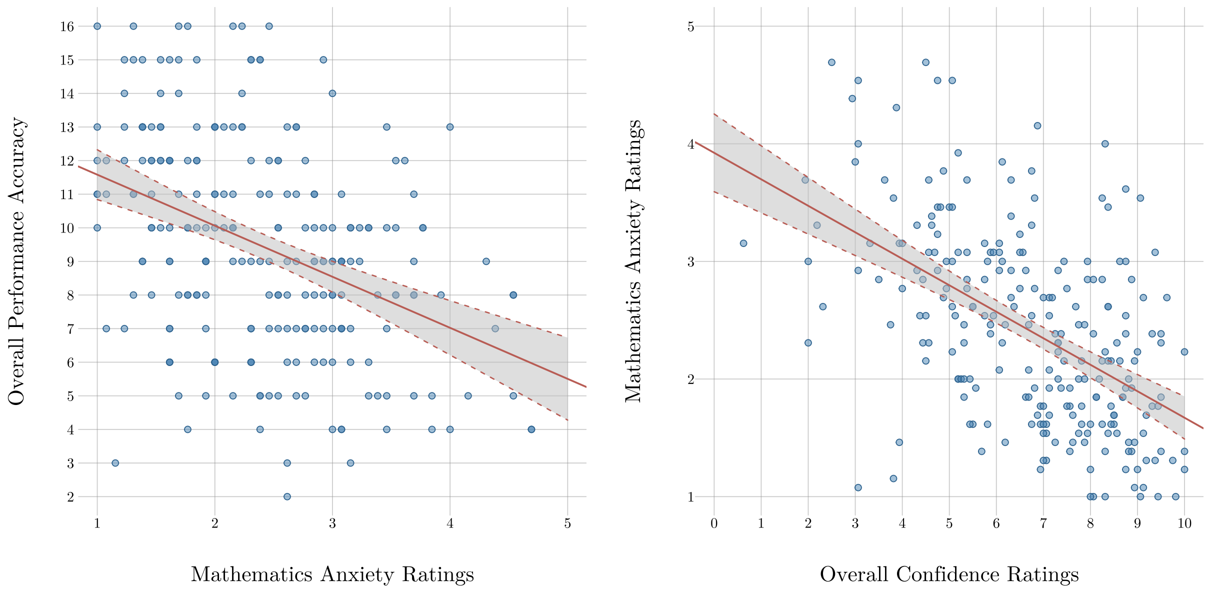
Hypothesis 4: Personality traits.

Primary Analysis

There was a significant negative correlation between levels of conscientiousness and performance accuracy on the numeracy and statistics items at the pre-test (Spearman rank correlation coefficient: $S = 2\,767\,475$, $p < 0.01$, $\rho = -0.232$).

There were no significant correlations between levels of openness and performance accuracy on the numeracy and statistics items at the pre-test (Spearman rank correlation coefficient: $S = 2\,159\,093$, $p = 0.5488$, $\rho = 0.039$) or between neuroticism and performance accuracy at the pre-test (Spearman rank correlation coefficient: $S = 2\,377\,024$, $p = 0.3735$, $\rho = -0.058$).

There was a significant positive correlation between levels of neuroticism and mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 1\,542\,694$, $p < 0.001$, $\rho =$



(a) $\hat{y} = 13.62 - 1.55x$, $R^2 = 13.3\%$
Overall performance accuracy (y) and mathematics anxiety ratings (x)

(b) $\hat{y} = 3.70 - 0.18x$, $R^2 = 21.1\%$
Mathematics anxiety ratings (y) and overall confidence judgments (x)

Figure 4.7 | Scatterplots illustrating the statistically significant Spearman rank correlations for mathematics anxiety ratings at the pre-test. We have included simple linear regression models to aid with graphical visualisation.

0.313).

There was not a significant correlation between levels of the agreeableness and difference in performance accuracy on the numeracy and statistics tests between the pre- and post-tests (Spearman rank correlation coefficient: $S = 52\,238$, $p = 0.0998$, $\rho = 0.194$).

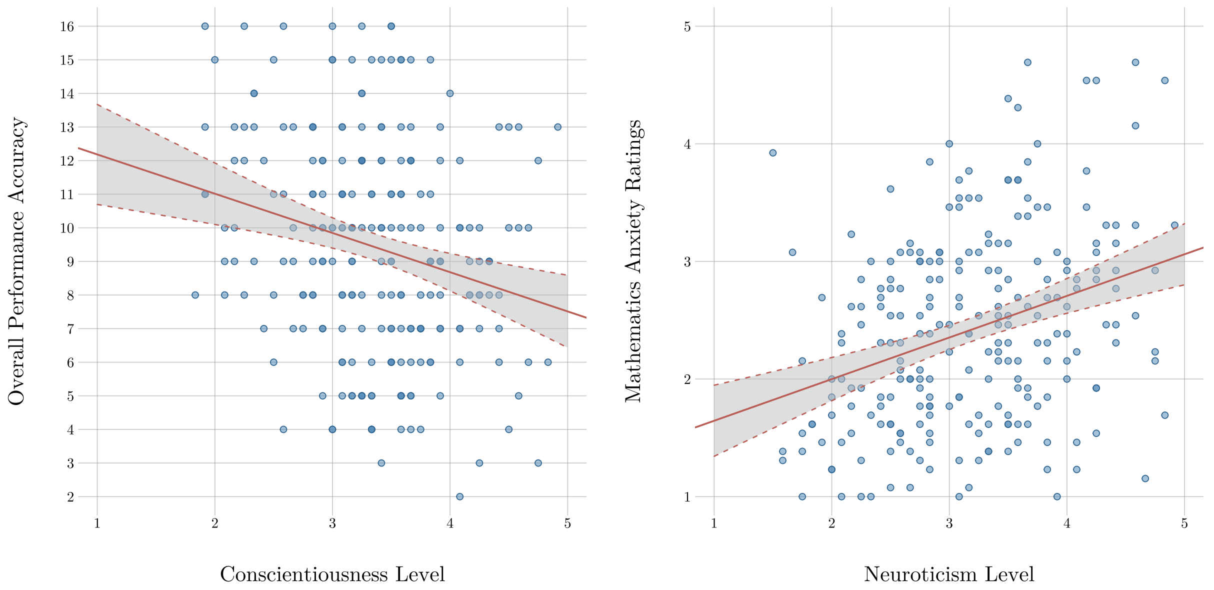
Secondary Analysis

There were no significant correlations found at the post-test between levels of specific personality traits and performance accuracy or mathematics anxiety. A summary of the results of the secondary analysis is given in Table 4.7.

4.2.2 Exploratory Analysis of Results

Path analysis models

The path analysis model for the pre-test is given in Figure 4.9. The model explained 53.8% of the variance within the numeracy performance score and 14.0% of the variance within the



(a) $\hat{y} = 13.35 - 1.17x$, $R^2 = 5.7\%$
Overall performance accuracy (y) and conscientiousness score (x)

(b) $\hat{y} = 1.29 + 0.35x$, $R^2 = 10.7\%$
Mathematics anxiety ratings (y) and neuroticism score (x)

Figure 4.8 | Scatterplots illustrating the statistically significant rank correlations for personality traits at the pre-test. We have included simple linear regression models to aid with graphical visualisation.

statistics performance score. In this model, the negative path coefficient for *Post-16 Mathematics* on *Numeracy Performance* indicates that absence of a post-16 mathematics qualification had a negative effect on numeracy performance scores.

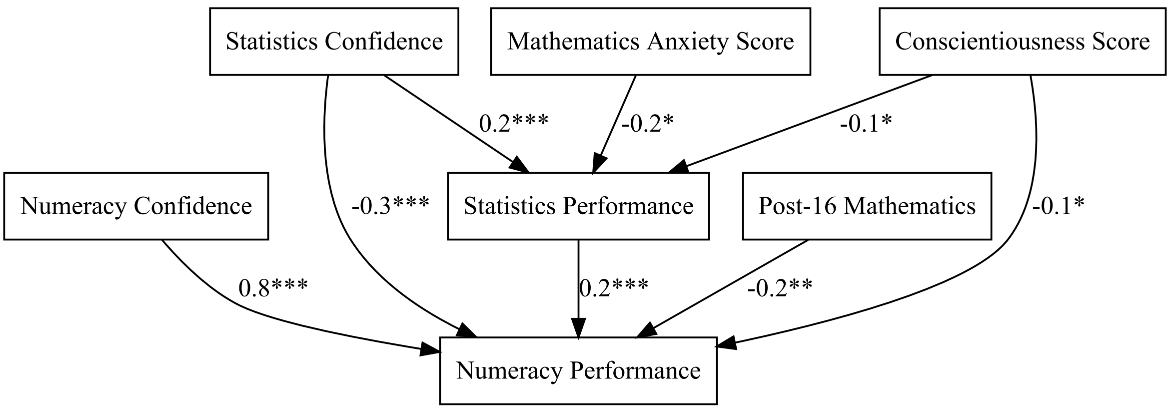


Figure 4.9 | Path analysis model for the pre-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $* * *$ (< 0.001).

The path analysis model for the post-test is given in Figure 4.10. The model explained 49.6% of the variance within the numeracy performance score and 21.3% of the variance within the

Table 4.7 | Secondary analysis performed on levels of personality traits showing Spearman rank correlations: S statistic, p-value and correlation coefficient ρ.

Personality trait	Variable	S	p-value	ρ
Conscientiousness	Performance accuracy at the post-test	79583	0.0527	-0.228
Conscientiousness	Difference in performance accuracy between the pre- and post-test	64565	0.9733	0.004
Openness	Performance accuracy at the post-test	52726	0.1139	0.187
Openness	Difference in performance accuracy between the pre- and post-test	63715	0.8858	0.017
Neuroticism	Performance accuracy at the post-test	68259	0.6561	-0.053
Neuroticism	Difference in performance accuracy between the pre- and post-test	77089	0.1089	-0.189
Neuroticisim	Mathematics anxiety at the post-test	54686	0.1864	0.156
Agreeableness	Difference in performance accuracy on the numeracy test between the pre- and post-test	46668	0.0164	0.280
Agreeableness	Difference in performance accuracy on the statistics test between the pre- and post-test	60230	0.5513	0.071

statistics performance score. In this model, the negative path coefficient for *Post-16 Mathematics* on *Numeracy Performance* indicates that absence of a post-16 mathematics qualification had a negative effect on numeracy performance scores.

The goodness-of-fit indices for the models in Figure 4.9 and Figure 4.10 are summarised in Table 4.8.

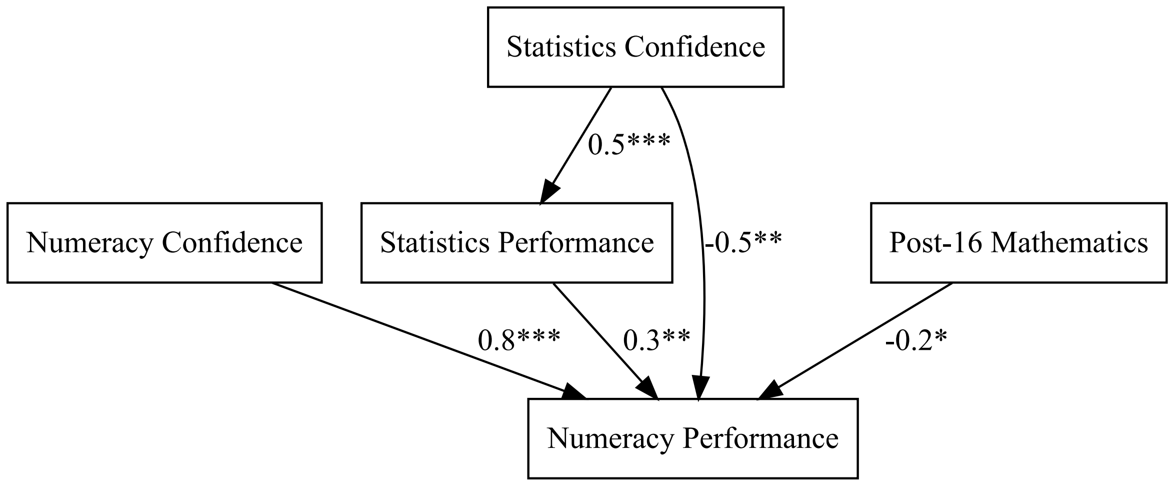


Figure 4.10 | Path analysis model for the post-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $* * *$ (< 0.001).

Table 4.8 | Goodness-of-fit indices for the path analysis models.

	RMSEA [90%CI]	χ^2	**SRMR**	**TLI**	**CFI**
Pre-test	0.000 [0.000, 0.109]	$\chi^2 = 2.991,\ df = 3,\ p = 0.393$	0.013	1.000	1.000
Post-test	0.000 [0.000, 0.164]	$\chi^2 = 0.631,\ df = 2,\ p = 0.729$	0.015	1.080	1.000

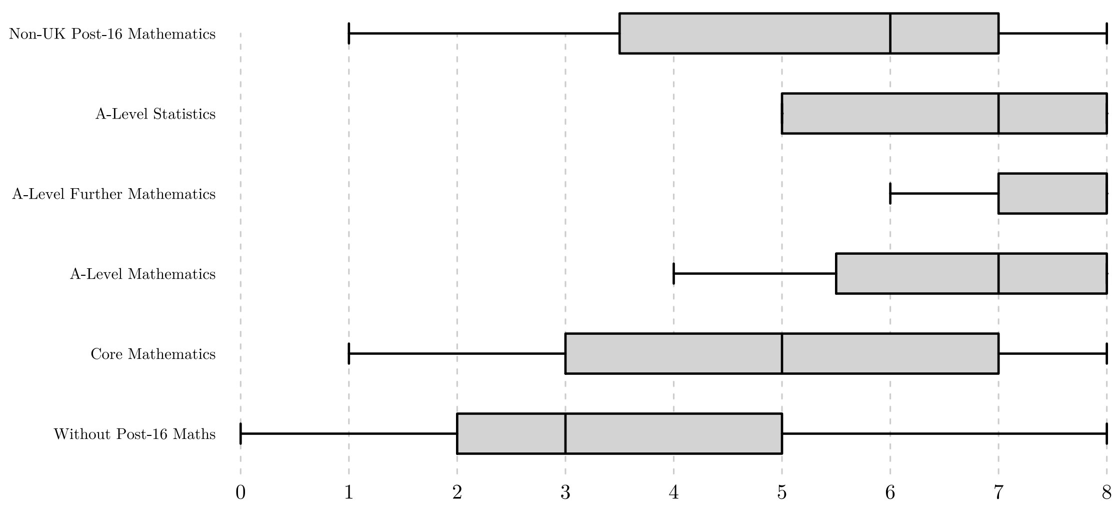
Differences between post-16 mathematics qualifications

Whilst our study was not powered enough to determine whether there were statistical differences between individual post-16 qualifications, we did perform preliminary visual analysis using boxplots to determine whether the differences tended to be driven by a single post-16 mathematics qualification. We include the analysis of these boxplots at the pre-test only since this had the higher sample sizes within each qualification.

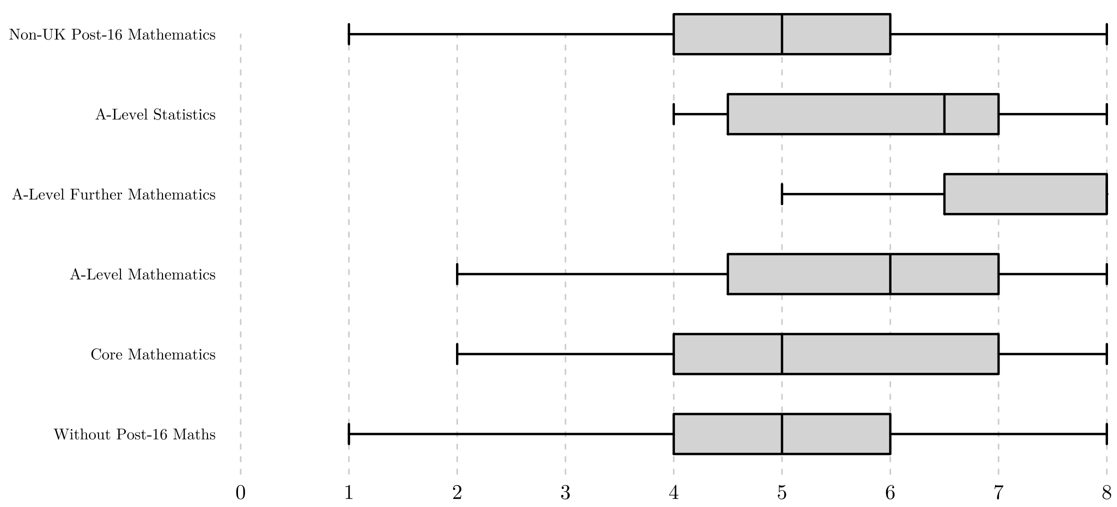
Figure 4.11 shows the differences in performance accuracy on each of the numeracy and statistics items. We observe that whilst A-Level Further Mathematics were the highest-scoring group, participants who had taken any post-16 mathematics qualifications remained higher than Group 2 on the numeracy questions. This implies that the differences which we found in Section 4.2.1 were not directly driven by one particular post-16 mathematics qualification. We can also observe that there was less of a difference in performance accuracy on the statistics items because Group 2 performed at a similar level on average as participants who had taken Core Mathematics or a non-UK post-16 mathematics qualification.

Figure 4.12 shows the confidence judgments on each of the numeracy and statistics items. We can see that the most confident group were the participants with A-Level Further Mathematics, however participants who had taken any post-16 mathematics qualification appeared to be more confident on each set of questions than Group 2.

Figure 4.13 shows the differences in mathematics anxiety ratings. We can observe the least anxious group appeared to be participants who had taken A-Level Further Mathematics, however most groups of participants who had taken a post-16 mathematics qualification appeared to be less anxious on average than Group 2. Again, this suggests that the differences observed in Section 4.2.1 were not directly driven by one particular post-16 mathematics qualification.

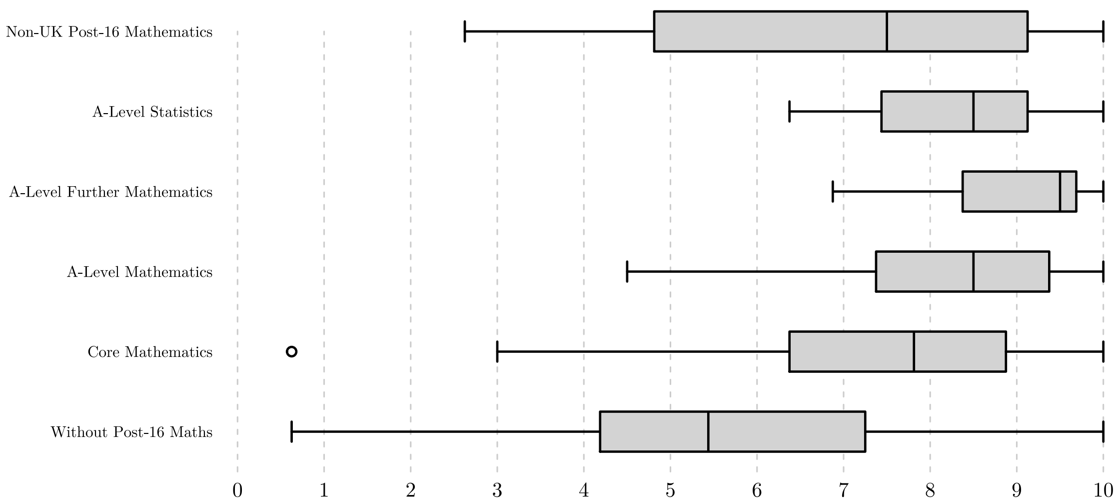


(a) Performance accuracy on the numeracy questions.

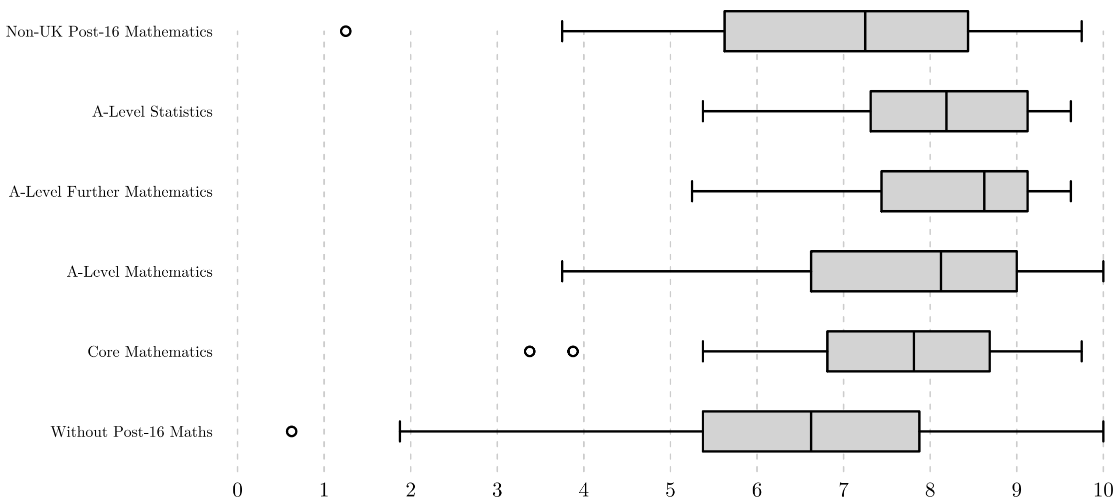


(b) Performance accuracy on the statistics questions.

Figure 4.11 | Boxplots of the performance accuracy at the pre-test for individual post-16 mathematics qualifications.



(a) Confidence judgments on the numeracy questions.



(b) Confidence judgments on the statistics questions.

Figure 4.12 | Boxplots of the confidence judgments at the pre-test for individual post-16 mathematics qualifications.

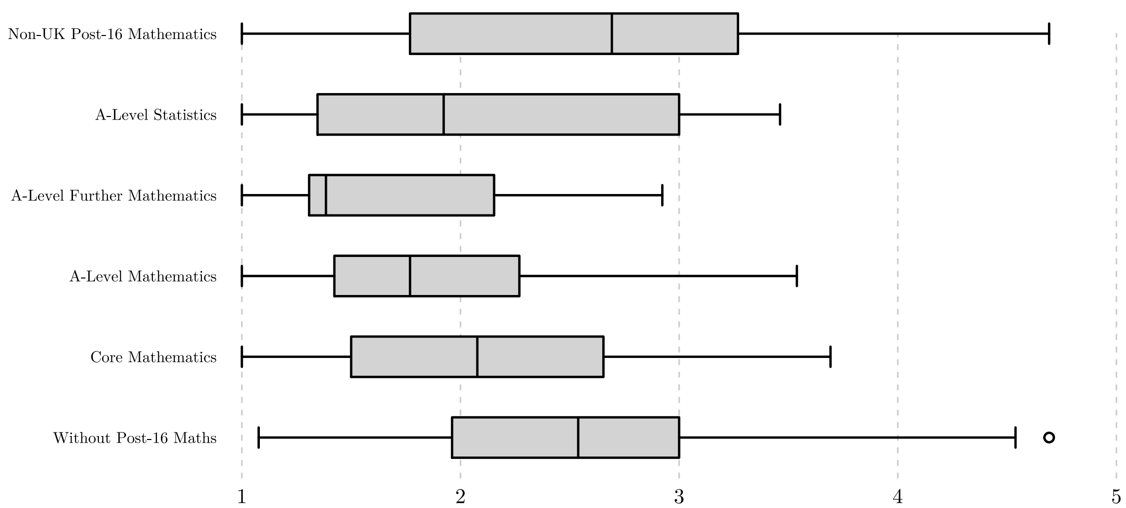


Figure 4.13 | Boxplots of the mathematics anxiety ratings at the pre-test for individual post-16 mathematics qualifications.

4.3 Discussion

This study aimed to investigate factors which predict quantitative performance in students who had just started an undergraduate course at university, and to see whether there were significant differences between a group of participants who had studied post-16 mathematics and a group of participants who had not.

Our results showed that having a post-16 mathematics qualification was a significant predictor of better overall performance accuracy which is perhaps unsurprising given that these participants were likely to have had regular practice with mathematics-based tasks at a higher difficulty level than GCSE in the time immediately before starting at university. Indeed, this was reflected by the fact that this group of participants were also more confident when answering questions in the numeracy and statistics test. However, instead of framing this section of the discussion from the perspective of the group who had studied a post-16 mathematics qualification, perhaps we should focus this from the group who had not. Not only did this group show poorer performance accuracy overall, but they were also associated with a higher level of mathematics anxiety. Indeed, mathematics anxiety has been shown to inhibit one's ability to engage with and learn mathematics-based tasks (Ashcraft et al., 1998; Dowker et al., 2016) which our evidence shows may have been further exacerbated by two years of not studying a mathematics qualification due to observable differences between these groups.

Crucially, our evidence shows that despite the fact that participants in our study were expected to study quantitative content between the pre- and post-test as part of their university degree course, we did not find strong evidence of an improvement in their performance. As such, we may conclude that a term of studying quantitative content at university is not sufficient enough to close the performance gap between those who have studied mathematics after the age of 16. Whilst some studies have suggested that this gap tends to close by the end of certain university degree courses (Adkins & Noyes, 2018), it still remains unclear at what point in a student's university degree having a post-16 mathematics qualification ceases to be an advantage. We should also consider that students experience feelings associated with the fear of failure and general anxiety as they adapt to university life (Ladejo, 2023) and so targeting students in their first term is important to limit long-term affects and prevent premature withdrawal from their course. One should note, however, that different quantitative modules were studied by participants between the pre- and the post-test which may account for differences in the types of knowledge and skills that were developed. Moreover, none of these modules were delivered with the specific aim to increase attainment on the numeracy and statistics questions within our survey tool. However, our survey tool attempted to test the underlying numeracy and statistics skills which one would expect would naturally improve when receiving further mathematics training.

Interestingly, when considering performance accuracy on the numeracy and statistics test individually, we found that participants who had studied a post-16 mathematics qualification only exhibited better performance on the numeracy section of the test with no significant performance differences found on the statistics section. When analysing the differences further, we see that participants who had not studied a post-16 mathematics qualification performed better, on average, on the statistics questions than the numeracy questions, thus closing the performance gap between the groups. This may be because the 2017 A-Level reforms required a greater level of quantitative skills to permeate into other subjects (Norris & Noyes, 2023). As such, it may be the case that many of the core statistics skills that we assessed in our statistics questions were met within other A-Level subjects, thus explaining the improved performance accuracy on the statistics questions compared to the numeracy questions. Alternatively, one must consider that the majority of our study population were taking a degree in Psychology which is noted as being a subject which requires a high level of statistical content The British Psychological Society (BPS) (2019). As such, if these participants had taken A-Level Psychology then they may been more familiar with these ideas associated with statistical reasoning. However, one should note from the visual analysis that participants without a post-16 mathematics qualification still had an median average score that was lower than other post-16 mathematics qualifications. Indeed, if one were to compare differences between A-Level Mathematics and Further Mathematics and participants without a post-16 mathematics, we could expect to see significant differences.

Whilst we did not explore age as a predictor since the majority of participants in our study were aged between 18-21, we did explore whether gender had an effect. We did not observe any significant associations for gender in the path analysis models, however these effects may been masked by the fact that the majority of the participants in our study were female (66%, 64%, 69% at the pre-test, post-test, pre-/post-test, respectively). Previous literature has highlighted that females tend to perform better than males in academic performance tasks (Pomerantz et al., 2002), despite the fact that they tend to experience higher levels of general anxiety (McLean et al., 2011). Whilst our evidence does not highlight such differences in mathematics-specific tasks, the number of students opting to take a post-16 mathematics qualification in the UK tends to be biased towards males (JCQ, 2023) so gender differences may be more complex than those observed here.

Since retrospective confidence judgments were collected in response to participant's answer to each numeracy and statistics question, this is an indirect predictor of performance. Indeed, we found that the positive correlation between performance accuracy and confidence suggested that participants were mostly successful in determining whether they had accurately identified the correct answer. In addition, confidence ratings were negatively correlated with mathematics anxiety which aligns with the negative correlation between performance and mathematics anxiety.

Certain personality traits also offered insights how participants were likely to perform. For example, we found that high levels of conscientiousness were associated with lower levels of performance accuracy which indicated that participants who were focused and systematic were less likely to perform well on the numeracy and statistics test. This is surprising given that mathematics tends to appeal to a logical and systematic way of thinking (A. Smith, 2004 [p. 11]) which aligns with general definitions of the conscientiousness trait as individuals with self-discipline and achievement-orientated (McCrae & Costa, 1995). Although we did not directly measure the stress or tension which a participant experienced whilst completing the mathematics and statistics questions, one could argue that this negative effect of conscientiousness with performance may be due to these individuals being motivated to perform well and so experienced a higher level of tension when completing mathematics-based tasks because of this. This has been evidenced in other studies where conscientiousness can result in higher levels of stress

(Cianci et al., 2010; Lin et al., 2014).

We found that neuroticism was positively correlate with mathematics anxiety which is unsurprising given that the neuroticism trait is closely associated with definitions of unease and worrying. This supports the findings which have evidenced the association between more general anxiety traits and neuroticism (Jylhä & Isometsä, 2006), so we have also evidenced that it is also true for mathematics anxiety, in particular.

It should be noted, however, that these correlations were not found at the post-test which might indicate that the sample size was too small at the post-test to detect significant correlations. One needs to be mindful that personality traits are shown to be stable among the age group of participants in our study (Bleidorn et al., 2019; McCrae & Costa, 1995) and so the absence of significant correlations with personality traits at the post-test was more likely to be explained by a smaller sample size.

We also performed preliminary visual analysis to determine differences between individual post-16 mathematics qualifications. One must be mindful that this analysis was performed with only a few individuals taking some of the post-16 qualifications which is why further analysis was not conducted on these sub-groups. Despite this, we observed that the differences between participants with and without a post-16 mathematics qualification are unlikely to be driven by a particular qualification. For example, we can see that each individual post-16 mathematics qualification seemed to have an advantage over not having studied a post-16 mathematics qualification in the areas of increased performance accuracy, lower levels of mathematics anxiety, and increased levels of confidence when completing mathematics-based tasks. In particular, we observed that participants with Core Mathematics appear to broadly on-par with participants who have studied post-16 mathematics qualifications in other countries. This is interesting since an aim of Core Mathematics was to plug the “mathematics gap” (DfE, 2013) caused by not studying any form of mathematics between the ages of 16-18 with a notable emphasis on the fact that the UK was behind other countries in terms of the proportions of students taking mathematics between these ages Hodgen et al. (2010). As such, if our preliminary results are correct, then it may appear that Core Mathematics is indeed succeeding in this respect.

5 2021-2022 Study

Chapter 5 Contents

This chapter describes the second study in this thesis which took place between October 2021 and February 2022. Similar to the 2019-2020 study discussed in Chapter 4, this study also consisted of a pre-test that was designed to collect data at the start of university and a post-test that was designed to collect data after one term of studying at university. This study was delayed by one year due to the outbreak of COVID-19 which caused us to change some of the data collection methods as well as the questions that would be asked. As such, we designed the study protocol to allow the survey to be conducted online in order to recruit participants.

5.1 Study Aims

This study took place in the midst of the COVID-19 pandemic and the majority of the participants would have had education that was disrupted by the COVID-19 pandemic. For example, many participants would have been in Further Education at the time of the pandemic and would have had lessons which took place remotely. Whilst some lessons did go ahead face-to-face these were only for a few weeks and students would have had to switch between remote and face-to-face lessons depending on the updated government guidance. In addition, many of these participants would not have sat physical exam papers during the summer of 2020 and thus grades would have had to be justified using Centre Assessed Grades. This led to a unique opportunity to collect evidence of quantitative performance at university from these participants who had had education adversely affected by COVID-19. This meant that this study differed slightly from the 2019-2020 study.

This study was conducted at a time when the University of Essex was using a combination of remote and face-to-face teaching due to the government restrictions imposed due to COVID-19. This hybrid approach to learning meant that a large proportion of potential participants would not be physically on campus and thus we had to design a study protocol which accounted for this. The University of Essex also imposed restrictions on the collection of data in lab environments which included social distancing and so we had to factor these associated risks with conducting an lab-based study. Thus, we elected to run an online study where participants were able to complete the survey via a link that was emailed to them at a time that was convenient to them.

5.2 Methodology

The study was approved by the ethics committee of the University of Essex and was conducted in accordance with the ethical principles formulated in the *Declaration of Helsinki* (World Medical Association, 2013). Participants gave informed consent and were reimbursed with a digital £10 Amazon voucher which was emailed to their university email address after completion of each of the pre-test and the post-test.

5.2.1 Bespoke Numeracy and Statistics Test

Unlike the study protocol in the 2019-2020 study, participants completed this study online and so we were not able to impose the same conditions that we could in a lab environment such as research assistants monitoring participants' completion of the survey. Whilst we gave explicit instructions to participants that they must not use any external mathematical solving tools such as calculators or mathematical solvers, we still chose to adapt the questions to control for this.

To decide which of the numeracy and statistics questions from the 2019-2020 Study needed to be adapted, we initially input each question into a combination of Google's search engine and common mathematical computer algebra systems such as Wolfram Alpha and Symbolab. This established that many of the statistics questions could be reused since they used information given in graphs or tables which were difficult for any of these methods to search and interpret. However, many of the numeracy questions involved routine calculations where answers could be found easily. A total of 11 numeracy and 6 statistics questions were required to be adapted or replaced.

Whilst we were modifying the numeracy and statistics questions, we decided to restructure the performance test to allow for 15 numeracy and 15 statistics questions. This was primarily because we were administering the study online and so we initially required a greater number of questions to ensure that quantitative performance was still being tested reliably. We required that the questions would still align to the skill areas calculation, conversion, estimation, algebra (numeracy questions) and estimation, calculation, statistical reasoning (statistics questions) as well as the two difficulty levels that was aimed to determine differences in ability between the groups with and without a post-16 mathematics qualification.

In order to decrease the likelihood of questions being easily searched through an online mathematics solver, we elected to use a framework of presenting participants with information followed by a task which required them to utilise this information. After writing the new set of questions, we tested each of them in the aforementioned Google searches and mathematical computer algebra systems in order to ensure that the answer could not easily be found using this method. We also attempted to ensure that the incorrect options would act as distractors so that the correct option could not easily be guessed as being the obvious choice.

5.2.2 Study Participants

The experiment recruited 119 first-year undergraduate students from nine departments at the University of Essex. Since this survey took place at a time where there was a mix of face-to-face and online teaching taking place, we had to primarily rely on email communication from respective departments to recruit target participants. Prior to the start of the study, we emailed the Directors of Education in each of the departments at the University of Essex with a short summary of the aims of the survey and requested if they could advertise the survey to their first-year undergraduate students via email distribution lists. Participants were initially incentivised with the opportunity to win one of 50 £10 Amazon vouchers on completion of both rounds of the survey. Due to a low response rate, we decided to advertise a change to the terms of the incentive in the first and third week of the pre-test, respectively: first, that participants would be guaranteed to receive a £10 Amazon voucher on completion of both the pre- and post-test; second, that participants would be guaranteed to receive a £10 Amazon voucher on completion of each of the pre- and post-test. Participants who had already completed the pre-test prior to these incentive changes were also notified that these terms of remuneration would automatically apply to them.

Participants who had positively engaged with the pre-test were directly emailed by the lead researcher and invited to complete the post-test. Two further reminder emails were sent at the start of each week to participants who had not yet engaged with the post-test to further encourage uptake. The demographic characteristics of the study population at the pre-test and the post-test are shown in Table 5.1.

We also detail the particular mathematics qualifications detailed by participants who stated that they studied mathematics between the ages of 16-18 in Table 5.2.

5.2.3 Study Materials

We anticipated that participants may disengage with a lengthy survey taken online and so we decided on the essential instruments to include in this survey. Since our original motivation for conducting this study described in Chapter 1 was performance accuracy in mathematics-based tasks, confidence and mathematics anxiety in relation to differences between participants with and participants without a post-16 mathematics qualification, we decided to focus on these as the main instruments to include in this online survey. We also saw the perceived impact of COVID-19 as a necessary measurement to include within this survey.

Numeracy test

Participants were given a set of 15 numeracy questions at the pre-test and another set of 15 questions at the post-test. Each of the numeracy questions at the pre-test were paired with a question at the post-test such that a participant would be expected to find the questions in a pair of a similar difficulty and utilise similar numerical skills, however the context of the question was changed. This was to overcome any potential learning effects of remembering questions between the pre-test and the post-test. The questions were divided into four skill areas: calculation; conversions; estimation; algebra. The difficulty of the questions was set such that all questions were intended to be accessible to participants who had studied GCSE Mathematics. Some questions were written such that participants who had studied a post-16 mathematics qualification would be expected to answer with higher accuracy than those who had not studied mathematics to this level. For each question, participants were given a set of four multiple-choice options with only one option being correct. The question order and the order of the multiple-choice options were randomised in an attempt to prevent participants from working together to answer the questions. Prior to starting the numeracy test, participants were

Table 5.1 | The demographic characteristics of the study population.

	Degree Course	Gender				Age		Post-16 Study		Post-16 Maths		Foundation Year	
		Female	Male	Other	Total	Md	(SD)	UK	Non-UK	With	Without	Yes	No
Pre-test	Biology	7	4	0	11	19	(2.5)	5	6	9	2	0	11
	Economics	2	7	0	9	19	(1.4)	6	3	8	1	3	6
	Government	4	1	0	5	19	(0.5)	4	1	2	3	0	5
	HSC	27	3	0	30	26	(5.1)	20	10	10	20	5	25
	Mathematics	3	8	0	11	19	(1.4)	8	3	10	1	1	10
	Pathways	1	1	0	2	26	(0.0)	2	0	0	2	1	1
	Psychology	24	6	0	30	19	(2.5)	25	5	11	19	6	24
	Sociology	9	3	0	12	18	(0.5)	10	2	1	11	0	12
	SRES	7	2	0	9	19	(2.9)	6	3	4	5	0	9
	Total	**84**	**35**	**0**	**119**	**19**	**(3.5)**	**86**	**33**	**55**	**64**	**16**	**103**
Post-test	Biology	4	2	0	6	19	(1.4)	2	4	5	1	0	6
	Economics	1	4	0	5	20	(1.6)	3	2	4	1	2	3
	Government	3	0	0	3	19	(0.0)	2	1	1	2	0	3
	HSC	11	1	0	12	26	(7.3)	9	3	3	9	2	10
	Mathematics	2	6	0	8	18	(1.5)	7	1	7	1	1	7
	Pathways	0	1	0	1	26	–	1	0	0	1	0	1
	Psychology	9	2	0	11	19	(2.9)	8	3	4	7	3	8
	Sociology	5	0	0	5	19	(0.8)	4	1	0	5	0	5
	SRES	3	1	0	4	22	(3.6)	3	1	1	3	0	4
	Total	**38**	**17**	**0**	**55**	**19**	**(4.0)**	**39**	**16**	**25**	**30**	**8**	**47**

Note: Data about a participant's age was collected at both the pre-test and the post-test: *Md* = median; *SD* = standard deviation. *Biology* = School of Life Sciences, *Economics* = Department of Economics, *Government* = Department of Government, *HSC* = School of Health and Social Care, *Mathematics* = Department of Mathematical Sciences, *Pathways* = Essex Pathways Department, *Psychology* = Department of Psychology, *Sociology* = Department of Sociology, *SRES* = School of Sport, Rehabilitation and Exercise Science.

Table 5.2 | Frequencies of participants who had studied post-16 mathematics qualifications.

Post-16 Mathematics Qualification	**Pre-test**	**Post-test**
Core Mathematics	3	1
AS-Level Mathematics	6	4
A-Level Mathematics	23	13
AS-Level Further Mathematics	1	1
A-Level Further Mathematics	5	3
AS-Level Statistics	3	2
A-Level Statistics	6	5
IB Mathematics Studies SL	0	0
IB Mathematics SL	0	0
IB Mathematics HL	0	0
IB Further Mathematics HL	0	0
Other UK Qualification	0	0
Non-UK Qualification	20	9

IB = International Baccalaureate, *SL* = Standard Level, *HL* = Higher Level. Note that this list does not represent unique numbers of participants since it was possible for participants to have taken more than one post-16 mathematics qualification.

instructed not to use aids such as a calculator or online question solver and were advised to spend approximately one minute answering each question. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the 15 items for overall performance accuracy scores. Question metadata such as the time taken to first select an answer, time taken to select their last answer, time taken to submit the page, and number of answers selected prior to submitting their response was also recorded, but this data was not shown to participants.

Statistics test

Similar to the numeracy test, participants were given a set of 15 statistics questions at the pre-test and another set of 15 statistics items at the post-test. Questions were paired with the same rationale as the numeracy test.

The questions were divided into three skill areas: calculation; estimation; statistical reasoning. The difficulty of the statistics questions was set in a similar way to the numeracy test such that all questions were intended to be accessible to participants who had studied GCSE Mathematics, with variation in difficulty that would differentiate participants who had studied post-16 mathematics. Each statistics question had four multiple-choice options apart from four statistics questions which had graphs consisting of multiple years or months and so more than four multiple-choice options were assigned to these questions. Only one of the given multiple-choice options per question was correct. The question order and the order of the multiple-choice options were randomised in an attempt to prevent participants from working together to answer the questions. To ensure consistency with the procedure for the numeracy test, participants were given the same set of instructions as the numeracy test regarding not using a calculator or online question solver and the amount of time to spend per question. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the 15 items for overall performance accuracy scores. The same question metadata as the numeracy questions were also collected for the statistics test.

Confidence judgments

After each numeracy and statistics question, participants were asked, "How confident are you that you gave the correct answer in the previous question?" and had to rate their confidence according to a four-point Likert scale (1 = *I am guessing*, 2 = *I am not confident*, 3 = *I am quite confident*, 4 = *I am very confident*). An overall confidence score for calculated by taking the mean average of all confidence ratings. Additional accuracy scores for the numeracy and statistics tests were calculated by coding each question as *accurate* (numeric value of 1: either high confidence and question correct, or low confidence and question incorrect) or *inaccurate* (numeric value of 0: either low confidence and question correct, or high confidence and question incorrect). These scores were then averaged to obtain overall accuracy scores for the statistics questions and for the numeracy questions which corresponded to the proportion of accurate judgments for each test. The thresholds for *high confidence* (confidence rating of 3 or 4) and *low confidence* (confidence rating of 1 or 2) were chosen based on the descriptions of the Likert scale that was shown to participants. Figure 5.1 shows the confidence scale which was asked after each of the numeracy and statistics questions.

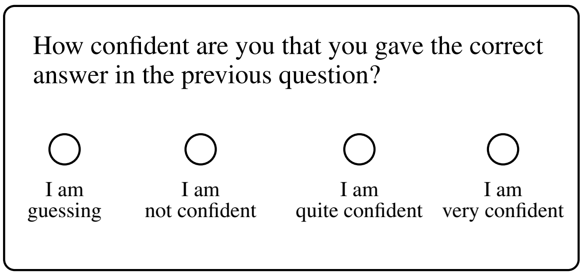


Figure 5.1 | The confidence scale which was asked after each of the numeracy and statistics questions.

Mathematics anxiety

Data about a participant's mathematics anxiety was collected using the Adult Everyday Mathematics Anxiety Scale (AEMAS, Rolison et al., 2016). The 13-item questionnaire asked participants to rate how anxious they would feel during the event specified (e.g., *Figuring how much a shirt will cost if it is 25% off*) on a five-point Likert scale (1 = *low anxiety*, 2 = *some anxiety*, 3 = *moderate anxiety*, 4 = *quite a bit of anxiety*, 5 = *high anxiety*). An overall mathematics anxiety score was obtained by calculating the mean average of all 13 ratings. The internal consistency (Cronbach's alpha) for our study was $\alpha = 0.911$ (pre-test) and $\alpha = 0.922$ (post-test) which is comparable to the $\alpha = 0.93$ reported by the authors.

COVID-19 Questionnaire

We devised a short questionnaire to determine the extent to which a participant perceived that COVID-19 had impacted their education. Participants were given two questions at the pre-test to establish whether they were in full-time education during the pandemic (*yes*, *no*) and, if so, where those lessons took place (*in a classroom*, *online*, *hybrid*, *no lessons*). For participants who had answered positively to these questions, they were subsequently given five statements involving the impact of COVID-19 on education (e.g., *COVID-19 has meant that I do not know as much content as I would have liked at the start of my degree course*) and were asked to rate their agreement on a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). Specific items were reverse coded and then a mean average of the five responses was calculated to determine the perceived impact of COVID-19 (1 = *low impact*, 5 = *high impact*). An additional two-items were given at the post-test to determine the transition to university (e.g., *The transition to university was made harder because of COVID-19*) and the same five-point Likert scale was used.

5.2.4 Study Procedure

The pre-test was open at the start of the autumn term between 2nd October 2021 and 14th November 2021 in order to ensure that participants would be exposed to a maximum of five teaching weeks of university teaching. The post-test was open at the start of the spring term between 17th January 2022 and 20th February 2022 which equates to the same amount of time as the pre-test.

The experiment was programmed using the online survey platform Qualtrics which participants accessed through a code that was emailed as part of the recruitment process. The first pages of the survey provided participants with an information screen about the study aims and a hyperlinked participant information sheet. Participants then gave informed consent by clicking the appropriate check-boxes and submitting their university email address. This email address was necessary to contact participants for the post-test, send the £10 Amazon voucher payment, and to match responses between the pre- and post-test through the use of a recoded participant number. Participants were also instructed that they should complete the survey in a time of between 10 minutes and 90 minutes: the upper bound was to encourage participants to complete the survey in a single session; the lower bound was to ensure that participants were positively engaging with the survey rather than selecting answers in rapid succession. Qualtrics would automatically place cookies in a user's browser which allowed a participant to be able to resume a partial attempt, however an incomplete survey attempt would automatically closed after four hours (which was the minimum time option available in Qualtrics after 90 minutes). This, in combination with a participant being required to enter their unique university email address, meant that a participant could only attempt the survey once.

At the post-test, the lead researcher emailed a unique survey link to each of the participants who had completed the pre-test. Reminder emails were subsequently sent at the start of each week that the study was open in order to encourage uptake from participants who had not yet engaged with the survey at the post-test.

5.2.5 The Course of the Experiment

The experiment started with a short demographic questionnaire followed by the numeracy test, the statistics test, the Adult Everyday Mathematics Anxiety Scale (AEMAS) and a short questionnaire regarding how participants perceived COVID-19 had impacted their education. Figure 5.2 displays the course of the experiment for the pre-test and the post-test.

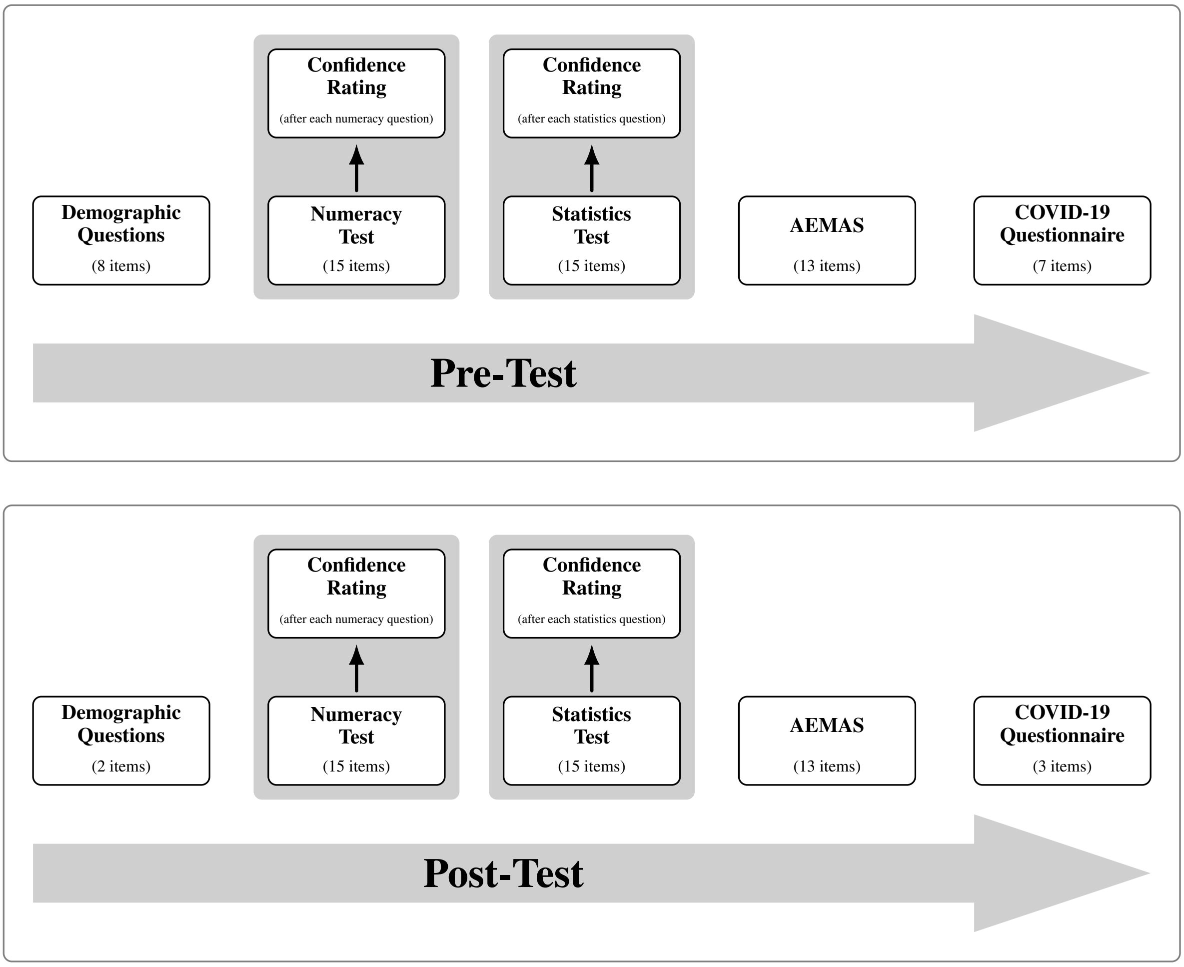


Figure 5.2 | The course of the experiment at the pre-test and the post-test. *AEMAS* = Adult Everyday Mathematics Anxiety Scale.

5.2.6 Sample Size Calculations

Given that 55 participants completed both the pre-test and the post-test, with 25 participants with and 30 participants without a post-16 mathematics qualification, we investigated whether the sample size possessed enough statistical power to assess differences between the groups. Considering two independent sample t-tests for 10 primary hypotheses which were Bonferroni corrected to give a significance level of $\frac{5\%}{10} = 0.5\%$ and using a standard deviation of 0.07 and a desired statistical power of 80%, we found that the sample size was powered enough to detect differences in accuracy as small as 7.5%.

5.2.7 Statistical Analysis

This study was pre-registered and so the main analysis followed the data analysis listed for the 13 hypotheses as given by Partner et al. (2021). We also formed path analysis models and explored additional relationships as exploratory analysis.

We initially tested for the assumption of normality in the data using a Shapiro-Wilk test on the groups of participants with and without a post-16 mathematics qualification. Most of the variables which were to be used in the primary analysis were found not to be normally distributed which we further verified using visual inspection of their histograms and measuring skewness and kurtosis (Table 5.3). Whilst a statistical transformation of the data may have allowed us to use parametric techniques, we instead chose to proceed with a more robust approach of non-parametric analysis. As such, the main analysis consisted of Wilcoxon signed-rank tests to determine differences between groups and Spearman rank-order correlation tests to determine correlations between variables. For the Wilcoxon signed-rank tests we report the test statistic W, the Bonferroni-adjusted p-value, the 95% confidence interval based on the scale of individuals, and the Cohen's d effect size. For the Spearman rank-order correlation tests we report the test statistic S, the Bonferroni-adjusted p-value, and the correlation coefficient ρ.

The exploratory analysis consisted of path analysis models using a combination of demographic and observed scores to predict the numeracy and statistics scores at each of the pre-test, post-test

Table 5.3 | Testing the normality assumptions for the variables performance accuracy, retrospective confidence judgments and mathematics anxiety for the groups with and without a post-16 mathematics qualification at the pre- and post-test.

		Post-16 Maths	W	p-value	Skewness	Kurtosis
Pre-test	Performance accuracy	With	0.9523	0.0291	-0.658	2.854
		Without	0.9770	0.2747	-0.207	2.467
	Confidence	With	0.9247	0.0020	-0.911	3.228
		Without	0.9624	0.0488	0.404	2.501
	Maths Anxiety	With	0.9116	<0.001	1.085	3.892
		Without	0.9728	0.169	-0.078	2.127
Post-test	Performance accuracy	With	0.9569	0.356	-0.516	2.796
		Without	0.9379	0.0799	0.494	2.133
	Confidence	With	0.8739	0.0052	-1.276	4.336
		Without	0.9641	0.3930	0.089	2.603
	Maths Anxiety	With	0.9102	0.0308	0.827	3.022
		Without	0.9689	0.5093	0.426	2.504

and pre-/post-test. Each model was subjected to goodness-of-fit statistics to assess how well the model fit the data, of which we primarily used the Root Mean Square Error of Approximation (RMSEA) and the χ^2 goodness-of-fit indices. We looked for a RMSEA value of less than 0.08 in order to be considered a good fit for the data and, likewise, a non-significant χ^2 value suggested evidence in favour of the null hypothesis that the model fits the data (Hu & Bentler, 1999). To control for effects of sample size on the RMSEA and χ^2 values, we also used additional fit indices of Standardised Root Mean Square Residual (SRMR), Tucker-Lewis Index (TLI) and the Comparative Fit Index (CFI), of which SRMR $<$ 0.08, TLI $>$ 0.95 and CFI $>$ 0.90 were considered as optimal thresholds to indicate that the model fits the data (Hu & Bentler, 1999). To ensure good model fit, we started with a hypothesised model including all variables and used a backwards selection method to remove non-significant variables until we achieved a model with goodness-of-fit indices within the desired ranges.

The data was analysed using the R language and environment for statistical computing and graphics version 4.3.2 (R Core Team, 2023) and the integrated environment R Studio version 2023.12.1+402. We used the R packages: lavaan (Rosseel, 2012); lavaanPlot (Lishinski, 2024); effsize (Torchiano, 2020); moments (Komsta & Novomestky, 2022).

5.3 Results

For brevity and clarity we will refer to Group 1 and Group 2 as:

Group 1: Participants who had studied a post-16 mathematics qualification.

Group 2: Participants who had not studied a post-16 mathematics qualification.

5.3.1 Pre-registered Main Analysis

Hypothesis 1: Performance accuracy in numeracy and statistics tests

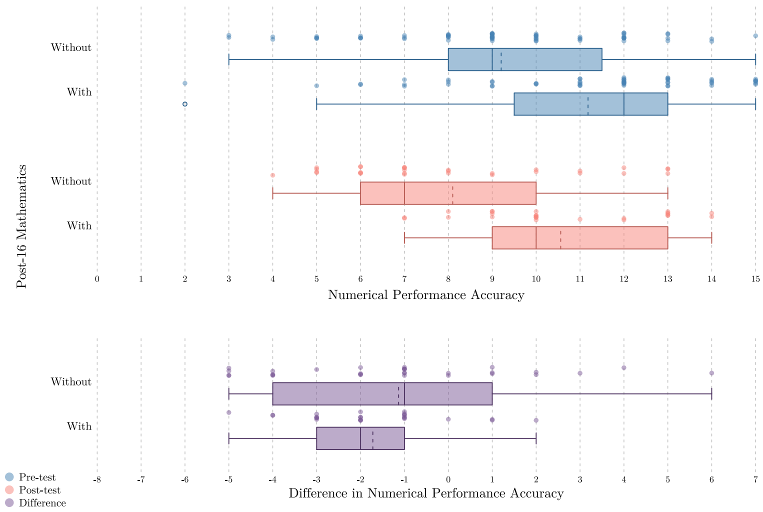
Primary Analysis

Group 1 had higher performance accuracy on the numeracy and statistics tests than Group 2 at the pre-test (Wilcoxon-test: $W = 2403.5$, $p < 0.001$, $95\%CI = [1.000, 5.000]$, $d = 0.604$) and the post-test (Wilcoxon-test: $W = 585.5$, $p < 0.01$, $95\%CI = [3.000, 8.000]$, $d = 1.113$).

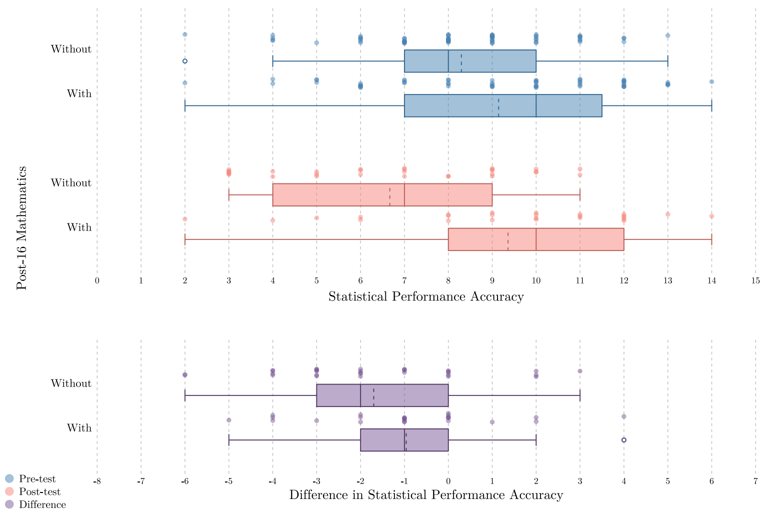
There was not a significant difference in the change in performance accuracy for either group between the pre-test and the post-test (Wilcoxon-test: $W = 400$, $p = 0.6770$, $95\%CI = [-0.500, 1.000]$, $d = 0.047$).

Secondary Analysis

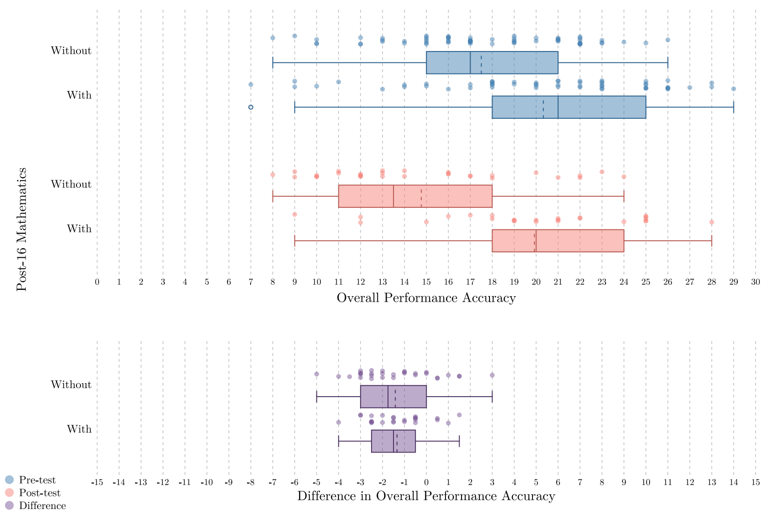
Group 1 were found to perform better on the numeracy tests than Group 2 at the pre-test (Wilcoxon-test: $W = 2469.5$, $p < 0.001$, $95\%CI = [1.000, 3.000]$, $d = 0.699$) and the post-test (Wilcoxon-test: $W = 573.5$, $p < 0.001$, $95\%CI = [1.000, 4.000]$, $d = 1.000$).



(a) Performance accuracy scores on the numeracy tests.



(b) Performance accuracy scores on the statistics tests.



(c) Overall performance accuracy scores.

Figure 5.3 | Boxplots showing the overall performance accuracy scores for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in performance accuracy scores between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

There was no significant difference between Group 1 and Group 2 on the statistics test at the pre-test (Wilcoxon-test: $W = 2121.5$, $p = 0.0527$, $95\%CI = [0.000, 2.000]$, $d = 0.338$). However, there was a significant difference at the post-test (Wilcoxon-test: $W = 569$, $p = 0.0212$, $95\%CI = [1.000, 5.000]$, $d = 0.961$).

There were no significant differences found in the changes in performance accuracy for either group between the pre-test and the post-test for the numeracy test (Wilcoxon-test: $W = 332$, $p = 0.4665$, $95\%CI = [-2.000, 1.000]$, $d = -0.249$) or the statistics test (Wilcoxon-test: $W = 451.5$, $p = 0.1936$, $95\%CI = [0.000, 2.000]$, $d = 0.340$).

Hypothesis 2: Retrospective confidence judgments

Primary Analysis

Group 1 was found to be more confident when answering the numeracy and statistics tests than Group 2 at the post-test (Wilcoxon-test: $W = 547.5$, $p = 0.0363$, $95\%CI = [0.167, 0.767]$, $d = 0.697$).

Performance accuracy was found to be positively correlated with confidence judgments at the pre-test (Spearman rank correlation coefficient: $S = 92\,108$, $p < 0.001$, $\rho = 0.672$).

Secondary Analysis

Group 1 was also found to be more confident when answering the numeracy and statistics tests than Group 2 at the pre-test (Wilcoxon-test: $W = 2478.5$, $p < 0.01$, $95\%CI = [0.233, 0.667]$, $d = 0.683$).

Group 1 were more confident than Group 2 when answering the numeracy questions at the pre-test (Wilcoxon-test: $W = 2507$, $p < 0.01$, $95\%CI = [0.267, 0.733]$, $d = 0.706$) and the post-test (Wilcoxon-test: $W = 566.5$, $p = 0.0258$, $95\%CI = [0.267, 0.867]$, $d = 0.902$). This was also the case on the statistics questions at the pre-test (Wilcoxon-test: $W = 2418$, $p < 0.01$, $95\%CI = [0.200, 0.600]$, $d = 0.566$) but not at the post-test (Wilcoxon-test: $W = 491$, $p = 0.5059$, $95\%CI = [0.000, 0.667]$, $d = 0.422$).

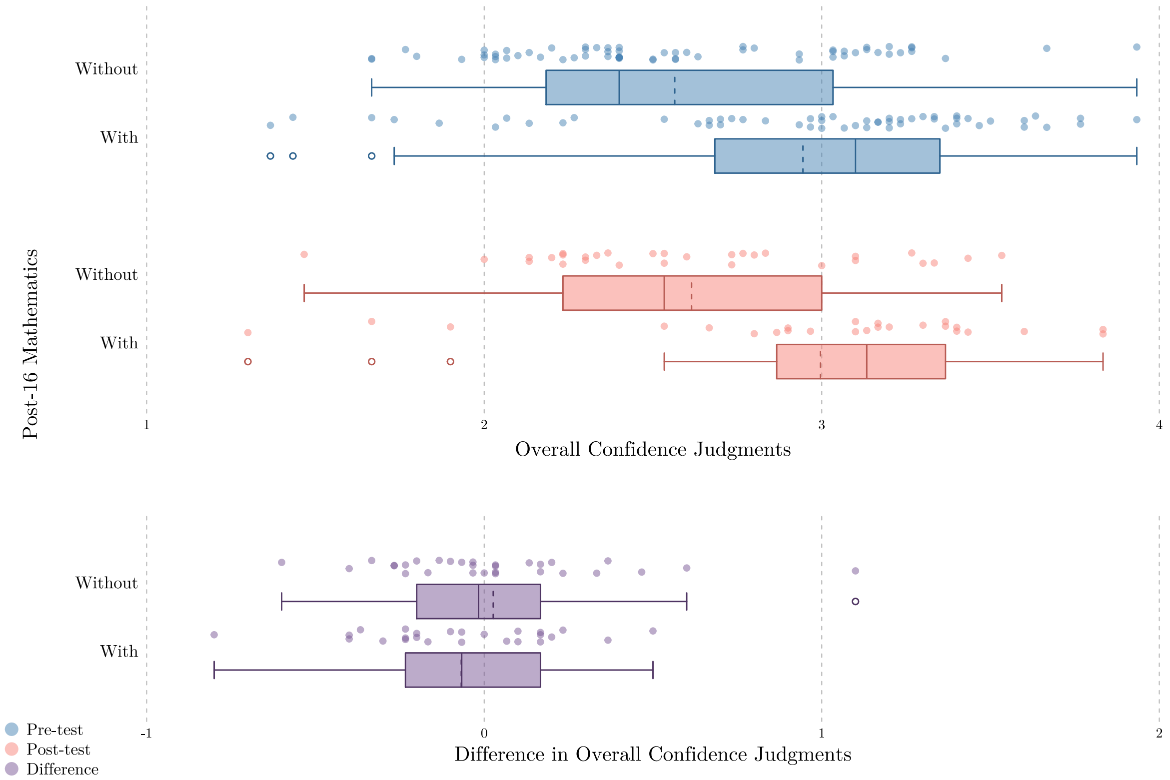


Figure 5.4 | Boxplots showing the overall confidence judgments for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in confidence judgments between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

Performance accuracy was found to be positively correlated with confidence judgments at the post-test (Spearman rank correlation coefficient: $S = 10\,054$, $p < 0.001$, $\rho = 0.637$). Moreover, there was a significant positive correlation between performance accuracy on the numeracy test and confidence judgments at the pre-test (Spearman rank correlation coefficient: $S = 84\,434$, $p < 0.001$, $\rho = 0.699$) and the post-test (Spearman rank correlation coefficient: $S = 10\,007$, $p < 0.001$, $\rho = 0.639$). There was also a significant positive correlation between performance accuracy on the statistics test and confidence judgments at the pre-test (Spearman rank correlation coefficient: $S = 156\,657$, $p < 0.001$, $\rho = 0.442$) and the post-test (Spearman rank correlation coefficient: $S = 12\,051$, $p < 0.001$, $\rho = 0.565$.

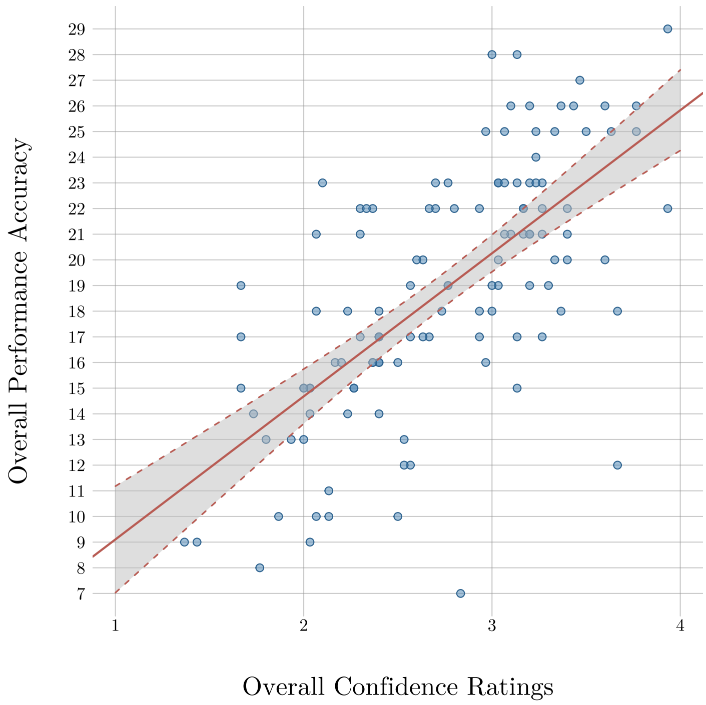


Figure 5.5 | Scatterplot showing the statistically significant correlation between the performance accuracy scores and the confidence judgments at the pre-test. This plot also shows a simple linear regression model $\hat{y} = 3.53 + 5.58x$, $R^2 = 44.9\%$ which has been added to aid with graphical visualisation.

Hypothesis 3: Mathematics anxiety

Primary Analysis

No significant differences were found between the mathematics anxiety levels of Group 1 and Group 2 at the pre-test (Wilcoxon-test: $W = 1240$, $p = 0.0560$, $95\%CI = [-0.846, -0.154]$, $d = -0.475$).

Performance accuracy was found to be negatively correlated with mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 419\,926$, $p < 0.001$, $\rho = -0.495$). Confidence was found to be negatively correlated with mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 421\,183$, $p < 0.001$, $\rho = -0.500$).

Secondary Analysis

No significant differences were found between the mathematics anxiety levels of Group 1 and Group 2 at the post-test (Wilcoxon-test: $W = 232$, $p = 0.3337$, $95\%CI = [-1.000, -0.077]$,

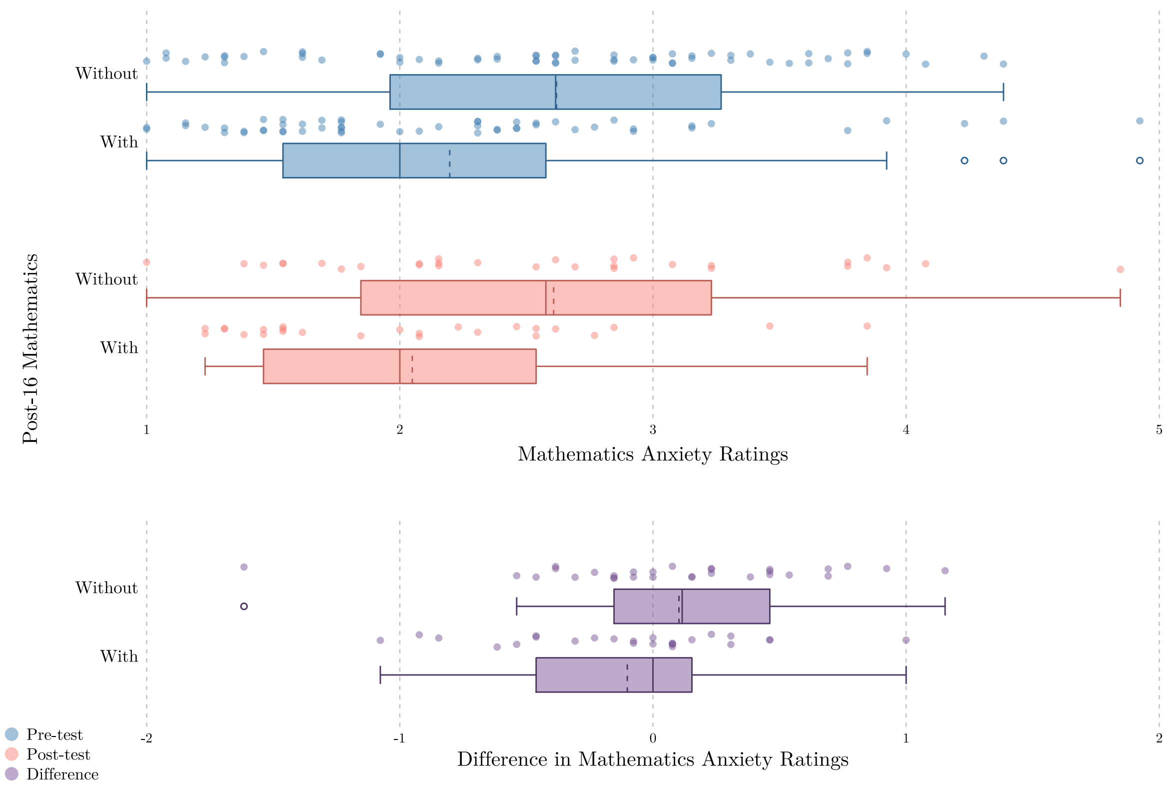


Figure 5.6 | Boxplots showing the mathematics anxiety ratings for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in mathematics anxiety ratings between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

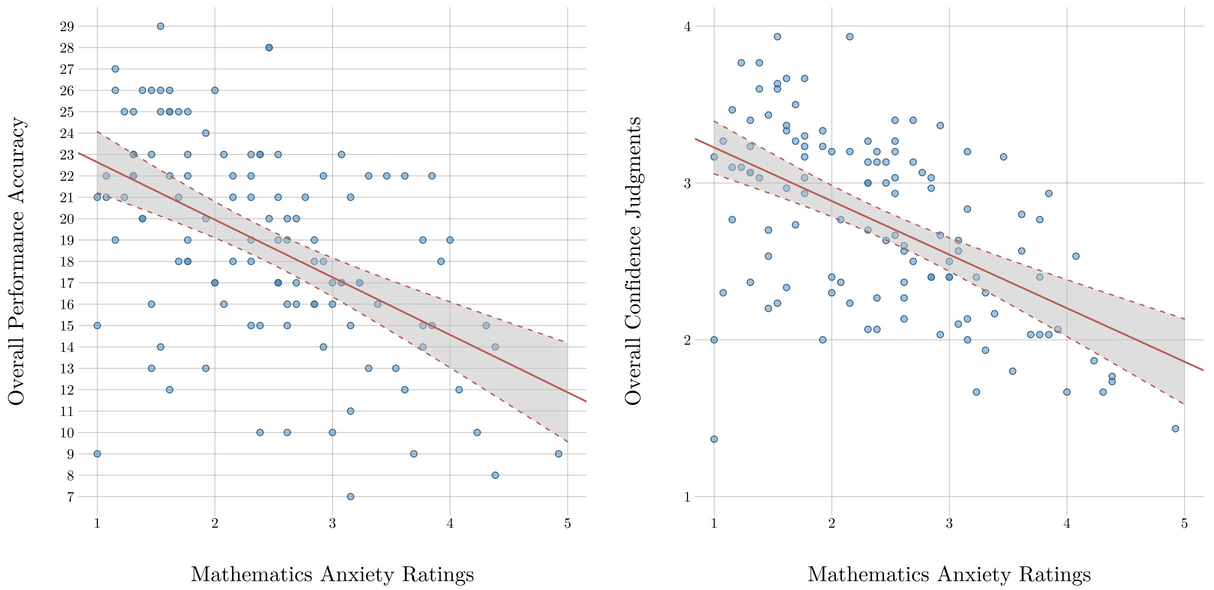
$d = -0.664$).

Performance accuracy was found to be negatively correlated with mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 40\,386$, $p < 0.001$, $\rho = -0.457$). Confidence was found to be negatively correlated with mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 41\,910$, $p < 0.01$, $\rho = -0.512$).

Hypothesis 4: COVID-19

Primary Analysis

There was no significant correlation found between levels of remote teaching and mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 108\,474$, $p = 0.0670$, $\rho = 0.191$). When considering participants in Group 1, there was still no significant correlation between these two variables (Spearman rank correlation coefficient: $S = 14\,888$, $p = 0.5886$,



(a) $\hat{y} = 25.33 - 2.69x$, $R^2 = 25.3\%$
Overall performance accuracy (y) and mathematics anxiety score (x)

(b) $\hat{y} = 3.57 - 0.34x$, $R^2 = 28.2\%$
Overall confidence judgments (y) and mathematics anxiety score (x)

Figure 5.7 | Scatterplots illustrating the statistically significant Spearman rank correlations for mathematics anxiety at the pre-test. We have added simple linear regression models to aid with graphical visualisation.

$\rho = 0.082$).

Secondary Analysis

There was also no significant correlation found between levels of remote teaching and mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 9837.7$, $p = 0.9794$, $\rho = 0.004$). When considering participants in Group 1, there was still no significant correlation between these two variables (Spearman rank correlation coefficient: $S = 1105.6$, $p = 0.1621$, $\rho = -0.355$).

5.3.2 Exploratory Analysis of Results

Path analysis models

The path analysis model for the pre-test is given by Figure 5.8. The model explained 52.9% of the variance within the numeracy performance score and 38.6% of the variance within the statistics performance score.

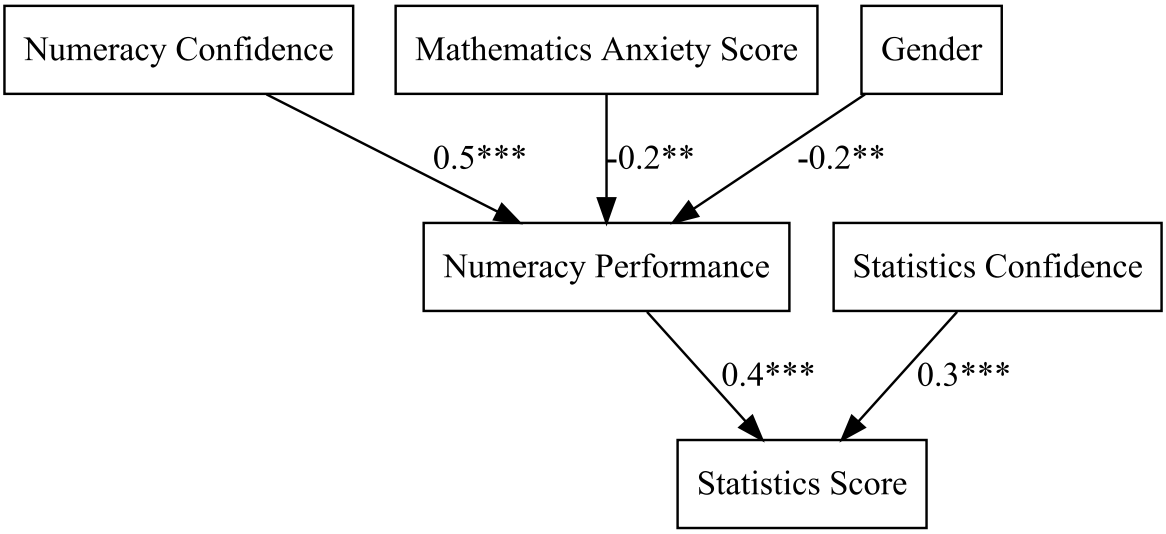


Figure 5.8 | Path analysis model for the pre-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $* * *$ (< 0.001).

The path analysis model for the post-test is given in Figure 5.9. The model explained 60% of the variance within the numeracy performance score, 42.8% of the variance within the statistics performance accuracy score and 30.2% of the variance within the mathematics anxiety score.

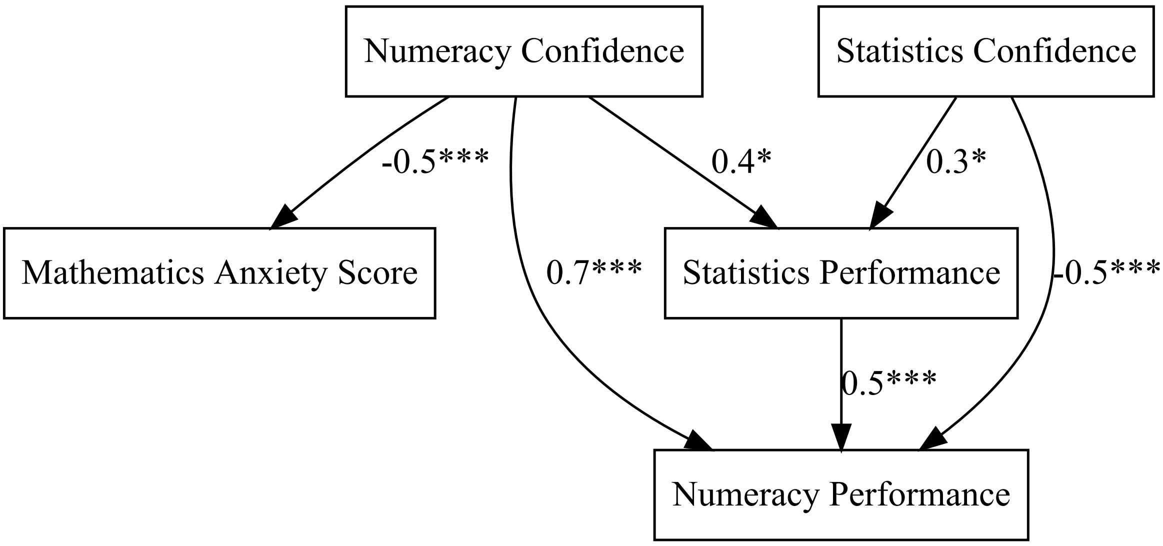


Figure 5.9 | Path analysis model for the post-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $* * *$ (< 0.001).

The goodness-of-fit indices for the models in Figure 5.8 and Figure 5.9 are summarised in Table 5.4.

Table 5.4 | Goodness-of-fit indices for the path analysis models.

	RMSEA [90%CI]	χ^2	SRMR	TLI	CFI
Pre-test	0.000 [0.000, 0.105]	$\chi^2 = 2.252,\ df = 4,\ p = 0.689$	0.017	1.028	1.000
Post-test	0.072 [0.000, 0.288]	$\chi^2 = 2.575,\ df = 2,\ p = 0.276$	0.035	0.973	0.994

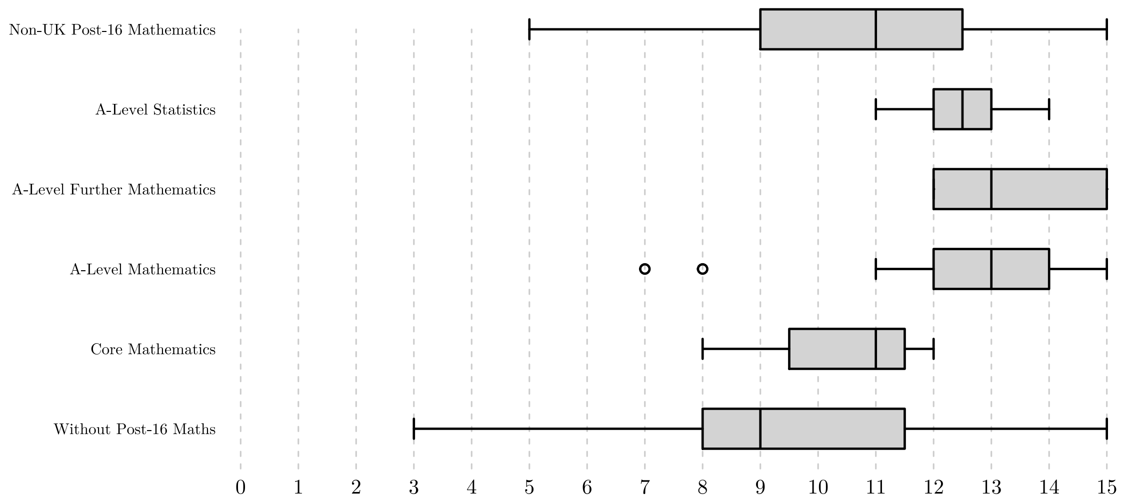
Differences between post-16 mathematics qualifications

Our study had low numbers of participants taking individual post-16 mathematics which meant that our study was not powered enough to detect statistical differences within these subgroups, however we did perform preliminary visual analysis using boxplots. This was so that we could attempt to determine whether any statistical differences found in Section 5.3.1 were driven by a particular post-16 mathematics qualification. Due to the attrition rate between the pre- and post-test, we performed this visual analysis using data from the pre-test only.

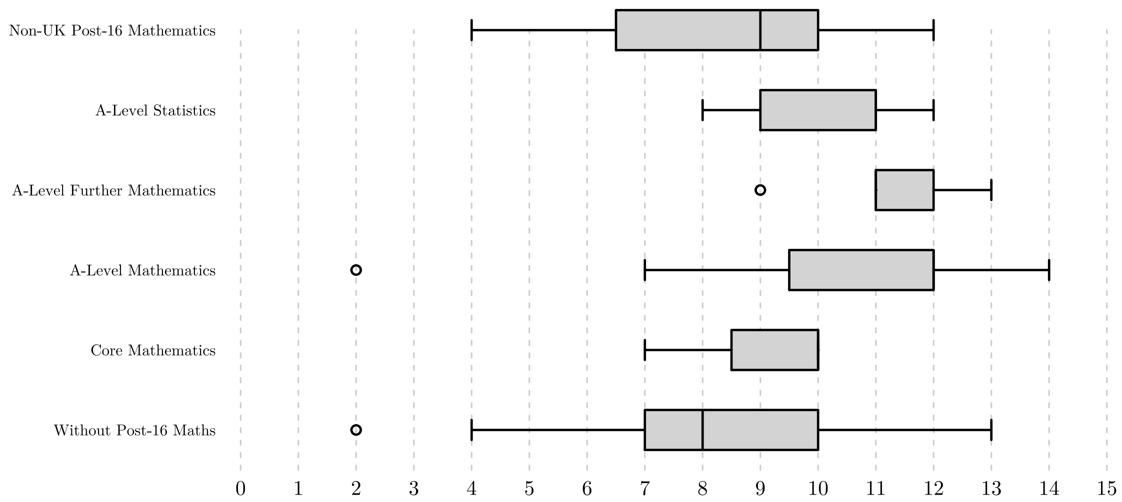
Figure 5.10 shows the differences in performance accuracy on each of the numeracy and statistics items. We can observe that although participants with an A-Level in Mathematics or Further Mathematics appeared to be the highest performing group on each set of questions, all post-16 mathematics qualifications appeared to exhibit an an advantage in performance accuracy over Group 2. We also observe a consistent difference on the statistics questions, even though this was not detected as being statistical significant within Section 5.3.1.

Figure 5.11 shows the confidence judgments on each of the numeracy and statistics items. We can observe that the confidence ratings on each of the numeracy and statistics questions were the lowest for Group 2. Indeed, these differences were found to be statistically significant in Section 5.3.1. We can observe from the boxplots that of the participants in Group 1, participants with Core Mathematics were the least confidence on both of the numeracy and statistics questions, however they still appeared to have higher ratings on average than participants without a post-16 mathematics qualification.

Figure 5.12 shows the differences in mathematics anxiety ratings. We can observe that Group 2 had the highest ratings of mathematics anxiety with all other post-16 mathematics qualifi-



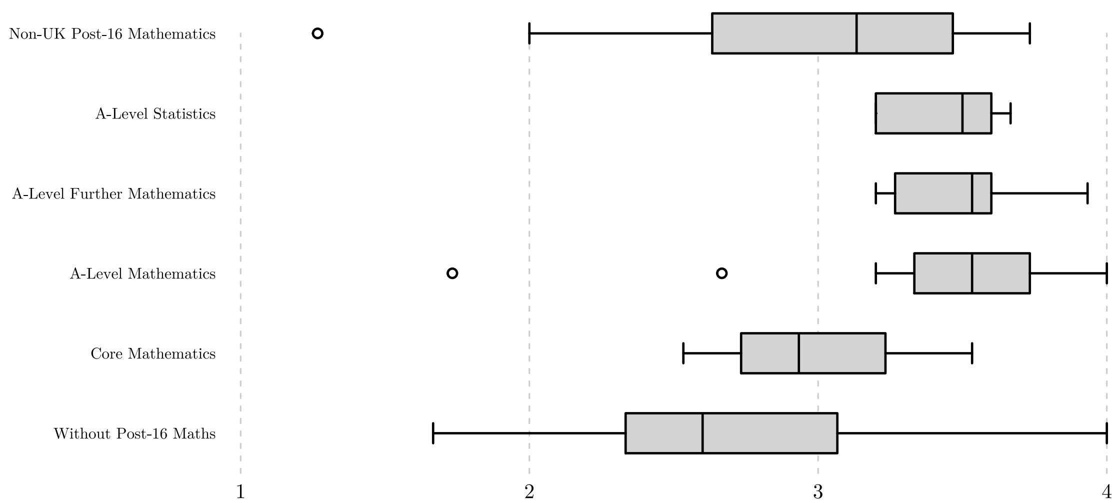
(a) Performance accuracy on the numeracy questions.



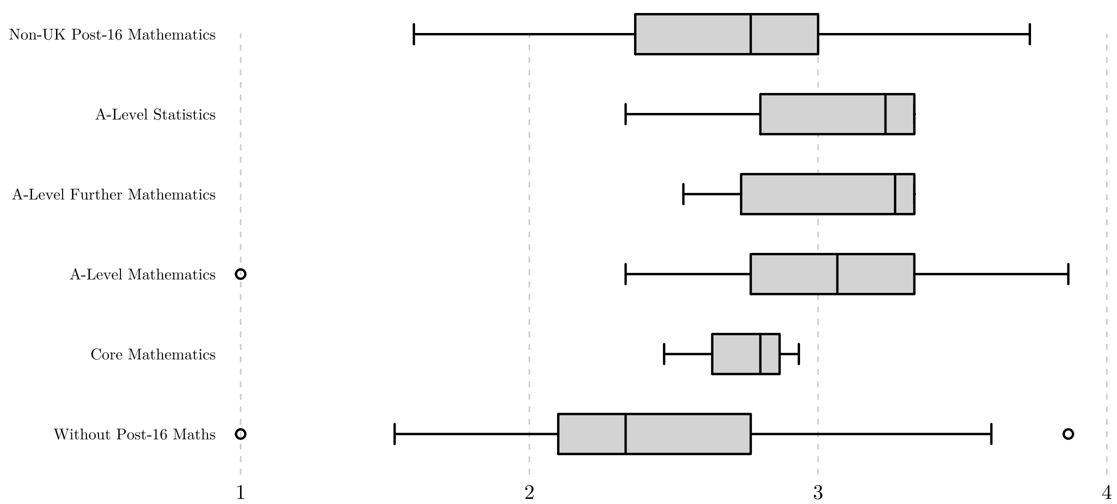
(b) Performance accuracy on the statistics questions.

Figure 5.10 | Boxplots of the performance accuracy at the pre-test for individual post-16 mathematics qualifications.

cations rating themselves as having lower mathematics anxiety. However, we did not find the differences between Group 1 and Group 2 to be statistically significant at the pre-test in Section 5.3.1. We can see from the boxplots that whilst participants with A-Level Mathematics had the lowest levels of mathematics anxiety, the other differences were much closer to the group without post-16 mathematics.



(a) Confidence judgments on the numeracy questions.



(b) Confidence judgments on the statistics questions.

Figure 5.11 | Boxplots of the confidence judgments at the pre-test for individual post-16 mathematics qualifications.

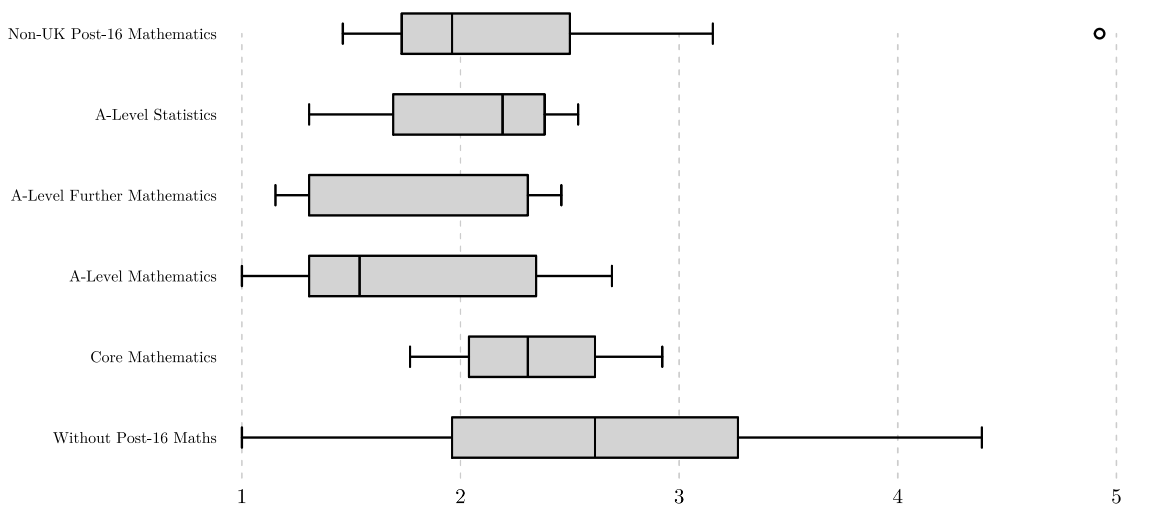


Figure 5.12 | Boxplots of the mathematics anxiety ratings at the pre-test for individual post-16 mathematics qualifications.

5.4 Discussion

This study aimed to characterise the predictors of mathematics performance in relation to an online sample of individuals who had just started studying a range of undergraduate degrees.

We found evidence that having studied a post-16 mathematics qualification was shown to have a positive influence on participants' performance at both the pre-test and the post-test. However, when considering the individual numeracy and statistics sections of the test, there was no significant difference in the statistics performance. Indeed, when considering the confidence judgments on these questions, we found that participants with a post-16 mathematics qualification had significantly higher ratings on statistics questions at the pre-test but not at the post-test. This is despite confidence judgments being positively correlated with performance accuracy on the statistics questions at both the pre- and post-test. When considering confidence judgments on the numeracy questions were significantly different at *both* the pre-test and the post-test. Since the statistics questions mostly required participants to use reasoning skills to make deductions from graphs, one may question whether our data suggests if post-16 mathematics qualifications adequately prepare students in this direction. Indeed, the mean average score on the statistics questions was found to be lower than on the numeracy questions suggesting that participants tended to struggle more with these questions. One also needs to consider that post-16 mathematics qualifications include a prescribed level of statistics content (for more information about the A-Level syllabus, see Ofqual (2017)) which means that participants with a post-16 mathematics qualification should be more familiar with these concepts and skills required to interpret data. This may help us to understand why participants with a post-16 mathematics qualification performed better at the pre-test. One may suggest that the lack of statistical difference at the post-test on the statistics questions may be due to studying such skills in their university degree course giving participants without a post-16 mathematics qualification time to catch up. We did not, however, find any evidence that this change occurred when looking at differences in performance accuracy between the pre- and post-test, which implies that this lack of statistical difference on the statistics questions may be due to some other factor.

Interestingly, having a post-16 mathematics qualification was not a significant factor within any of the path analysis models, however there were gender differences which were explained at the pre-test with females showing poorer performance on the numeracy questions. Although some literature reports that there are gender differences between mathematics anxiety (Devine et al., 2012), we did not find any such differences in our path analysis models.

Whilst we found significant correlations between performance accuracy and mathematics anxiety as well as with confidence judgments and mathematics anxiety, we did not find differences between the mathematics anxiety levels of the group of participants with a post-16 mathematics qualification compared to the group without. This is surprising given that the group of participants with a post-16 mathematics qualification would have engaged with mathematics regularly prior to starting to university and, thus, should be more familiar with completing mathematics-based tasks than their counterparts. When looking at the mean average mathematics anxiety ratings for each group, we see that the group without a post-16 mathematics qualification did not rate themselves as having high levels of mathematics anxiety which put them closer to the group who had studied a post-16 mathematics qualification. However, we can see that the standard deviations suggest that the group without a post-16 mathematics qualification had a much larger spread in their mathematics anxiety ratings than their counterparts which means that there was more variation in their scores. Indeed, we also performed visual analysis to identify differences between individual post-16 mathematics qualifications which supports the conclusion that having studied mathematics between the ages of 16-18 results in generally less-anxious individuals. Interestingly, this visual analysis also suggested that participants with a non-UK post-16 mathematics qualification had a larger range in their mathematics anxiety ratings, similar to participants without a post-16 mathematics qualification.

One also remember that this study was conducted at a time where COVID-19 caused a high level of disruption to one's education and so it is likely that a high proportion of teaching would have taken place remotely. This likely caused stress and anxiety to the learning environment and the way in which one engaged in education.

The path analysis models showed broadly similar causal relationships between variables at the pre-test and the post-test, with the exception of the gender variable not remaining significant at the post-test. However, the structure of certain paths changed between the pre-test and the post-test. Namely, individual numeracy and statistics confidence judgments were a significant predictor of their respective questions, however they were able to predict the other at the post-test (that is, numeracy confidence positively predicted statistics performance, and statistics confidence negatively predicted numeracy performance).

When considering changes between the pre-test and the post-test, we did not find any statistically significant differences or correlations. Indeed, the path analysis model also did not yield any significant causal relationships. Whilst the level of attrition between the pre- and post-test may have played a part, we might also consider that one term of university study has little effect on the changes in performance, confidence and mathematics anxiety. This is important since there were some differences found between group of participants with and without a post-16 mathematics qualification, namely with regards to mathematics ability and confidence. Hence, our results show that these differences tend to remain after the intervention of a term's study at university.

We also performed visual analysis in an attempt to indicate differences between individual post-16 mathematics qualifications. We observed that of the differences in the preregistered analysis between the groups on performance accuracy, mathematics anxiety and retrospective confidence judgments, were unlikely to have been driven by one particular post-16 mathematics qualification. Indeed, whilst participants with A-Level Mathematics and Further Mathematics tended to have the largest difference from participants who had not studied post-16 mathematics, some smaller differences could still be observed with other post-16 mathematics qualifications being better-performing, lower in their mathematics anxiety ratings and higher in their confidence judgments. This preliminary analysis suggests that participants who had studied any mathematics qualification between the ages of 16-18 are at an advantage in these areas over participants who had not. Of course, whilst this indicates differences, one would have to verify this with a similar study with a larger sample size which would allow further sub-group analysis.

We did not find sufficient evidence to suggest that levels of remote teaching had an association with mathematics anxiety levels, even for the group who had studied a post-16 mathematics qualification and, thus, were more likely to have engaged in mathematics during the COVID-19 pandemic. This may be because mathematics anxiety is a trait which is developed over a longer period of time than the 18 months since COVID-19 had started. This meant that the strongest predictor of mathematics anxiety was performance accuracy.

6 2022-2023 Study

Chapter 6 Contents

6.1 Study Aims

This study took place after the COVID-19 pandemic and as such the majority of the restrictions had been lifted and university's had returned to face-to-face study. This was a hybrid study consisting of a lab-based study which was conducted under the supervision of research assistants and recruited participants at the University of Essex and online study which recruited participants at 14 other UK university institutions and these participants could complete the survey at a time which was convenient to them. Since the method of recruitment and completion varied for each study, we elected to analyse the results separately.

6.2 Methodology

The study was approved by the ethics committee of the University of Essex and was conducted in accordance with the ethical principles formulated in the *Declaration of Helsinki* (World Medical Association, 2013). Participants gave informed consent and were reimbursed with a digital £10 Amazon voucher which was emailed to their university email address after completion of each of the pre-test and the post-test.

6.2.1 Bespoke Numeracy and Statistics Test

The numeracy and statistics questions used in this study were a subset of those used in the 2021-2022 Study (Chapter 5). This was because the part of this study that recruited participants from other universities would need to be run online and so we needed questions which were designed for this purpose. We performed a selection method to choose eight numeracy and eight statistics questions to use at each of the pre-test and post-test. We required that questions had four questions of Level 1 difficulty (aimed at participants with a GCSE Mathematics qualification) and four questions of Level 2 difficulty (aimed at participants with a post-16 mathematics qualification) whilst still aligning to the skill areas that were used in both the 2019-2020 Study and the 2021-2022 Study. In this subsection we outline the selection method in detail. It should be noted that the selection method used here follows similar procedure and the same criteria to the selection method used in Section 4.1.1, however we had to slightly vary the procedure in Stage 2 in this subsection by using a manual selection/rejection method in order to achieve a set of items that fit the imposed criteria.

We formed two groups of participants consisting of those with and those without a post-16 mathematics qualification and analysed the mean performance accuracy per question for each group at the pre-test and the post-test (Table 6.1). We then grouped the numeracy questions into four groups and the statistics questions into three groups according to the skills which the question was designed to assess. In the event that a question was not uniquely defined by one skill group, we allowed this question to appear multiple times in each of its respective skill groups.

Stage 1: we aimed to reject one question from each group which had the highest accuracy between all groups of participants (i.e., with and without post-16 mathematics at both the pre-test and the post-test). This was because we aimed to find evidence of differences between the groups of participants with and without a post-16 mathematics qualification and so questions which showed a similarly high performance accuracy across all participants did not fulfil this purpose. We achieved this by using a threshold test with 10% decrements to remove questions where high proportions of participants had answered the questions correctly, thus failing to show the differences that we were interested in investigating. We started with a threshold of 90% (i.e., more than 90% of participants with and without a post-16 mathematics qualification answered the question correctly at the pre-test and the post-test) and rejected the questions in each skill group where all accuracy scores were above this threshold. If we failed to reject any questions in the group, we changed the threshold to 80% and then 70% if we still failed to reject any questions in the skill group. In the event that more than one question in the group was rejected by our threshold test, we would reject all the associated questions, providing that at least one question would still remain in the group. There were no instances where we rejected all questions in the group using this threshold test. We did not use a threshold below 70% in our first iteration since we believed that this would show the required differences that we were interested in investigating. We did, however, implement subsequent arguments in our selection method to account for this. This threshold test failed to reject any questions from Numeracy Estimation, Statistics Estimation, Statistics Statistical Reasoning.

Stage 2: we considered the differences in performance accuracy between participants with and without a post-16 mathematics qualification for each skill group. We rejected questions where this difference was less than 10% at both the pre-test and the post-test on the basis that this did not show substantial differences between the two groups of participants. If we failed to reject any questions in the group, we would increase this difference to 20%. We did not use a difference of more than 20% since we believed that this would account to a sufficient difference in performance accuracy. In the event that more than one question was rejected from each skill group we would reject all questions according to the difference rule, providing that there was at least one question that remained in each group.

We then analysed the remaining questions and assessed how well they fit our original criteria. For the set of numeracy items, we were left with eight questions, of which four were Level 1 and four were Level 2. There was also at least one question from each of the four skill groups. As such, we were satisfied that we had found a set of eight questions which fulfilled our criteria. For the set of statistics items, we were left with nine questions, of which three were Level 1 and six were Level 2. This meant that we needed to manually remove two questions of Level 2 difficulty and reintroduce one rejected question of Level 1 difficulty.

There were two Level 1 statistics questions that were rejected: S4 and S8. We investigated the reasons for rejection in more detail. S4 was rejected in *stage 1*, observing that the question had accuracy scores of above 90% and 80% at the pre-test and post-test, respectively. On the other hand, S8 had lower accuracy ratings and was instead rejected at the second stage because the difference in accuracy between participants with and without a post-16 mathematics qualification was less than 10% at both the pre-test and the post-test. Since S8 held up to scrutiny from the first threshold test and only failed on the difference test, we decided to include S8 over S4 for this reason.

Table 6.1 The mean accuracy scores for the questions from the 2021-2022 Study.

Question	Skill(s)	Difficulty	Pre-test Accuracy		Post-test Accuracy	
			With Post-16 Maths	Without Post-16 Maths	With Post-16 Maths	Without Post-16 Maths
N1	Conversion, Calculation	Level 1	80%	56%	72%	30%
N2	Calculation	Level 1	69%	47%	76%	63%
N3	Algebra	Level 1	78%	48%	76%	53%
N4	Algebra, Conversion	Level 2	40%	30%	20%	7%
N5	Conversion, Estimation	Level 2	45%	33%	64%	43%
N6	Conversion, Calculation	Level 1	89%	80%	60%	57%
N7	Conversion, Calculation	Level 1	95%	89%	84%	87%
N8	Conversion, Estimation	Level 2	84%	83%	56%	57%
N9	Calculation	Level 1	93%	88%	100%	83%
N10	Algebra, Calculation	Level 1	89%	75%	100%	83%
N11	Algebra	Level 2	44%	19%	56%	10%
N12	Conversion, Calculation	Level 1	87%	62%	96%	60%
N13	Conversion, Estimation	Level 2	65%	56%	84%	60%
N14	Conversion, Estimation	Level 2	75%	72%	92%	57%
N15	Conversion, Calculation	Level 1	85%	83%	84%	70%
S1	Calculation	Level 2	44%	25%	80%	63%
S2	Estimation	Level 2	49%	33%	68%	50%
S3	Estimation	Level 1	76%	66%	76%	47%
S4	Calculation	Level 1	95%	92%	80%	83%
S5	Statistical Reasoning	Level 1	67%	86%	96%	93%
S6	Statistical Reasoning	Level 1	71%	77%	64%	43%
S7	Estimation	Level 2	55%	38%	60%	43%
S8	Statistical Reasoning	Level 1	69%	78%	36%	27%
S9	Statistical Reasoning	Level 2	89%	89%	12%	10%
S10	Statistical Reasoning	Level 2	64%	50%	40%	23%
S11	Estimation, Statistical Reasoning	Level 2	40%	33%	76%	33%
S12	Statistical Reasoning	Level 2	65%	38%	72%	50%
S13	Statistical Reasoning	Level 2	42%	33%	80%	33%
S14	Calculation	Level 2	69%	66%	64%	37%
S15	Calculation	Level 2	20%	28%	32%	30%

For convenience, questions are numbered here to correspond with the order given in Chapter B. Numeracy and statistics questions are labelled with the prefix *N* and *S*, respectively. The respective difficulty of each question is either *Level 1* being an easier standard which all participants should be able to access, or *Level 2* being a harder standard which is more accessible to participants with a post-16 mathematics qualification. The accuracy percentages were calculated as the mean number of participants in each group that got the correct answer on the question in the 2021-2022 Study.

To choose which two Level 2 statistics questions to further reject, we observed that the skill groups *calculation* and *estimation* only had two questions in each (of which S11 also fell into *statistical reasoning* skill group), whereas the *statistical reasoning* skill group had five questions which did not fall into any other skill group. As such, we argued to include the associated questions S1, S3, S11 and S14 which fell into the minority skill groups *calculation* and *estimation*. Of the questions remaining, S5 and S6 were rated as Level 1 difficulty so we elected to keep these questions since they did not fit the purpose of this additional step. This left S10, S12 and S13 which were Level 2 questions belonging only in the *statistical reasoning* skill group and would form the subset from which we aimed to reject two of these questions.

S10 showed a decrease in performance accuracy for both participants with and participants without a post-16 mathematics qualification. The question involved matching the correct box plot to the cumulative frequency graph. The question at the pre-test involved skewed data, whereas the question at the post-test showed symmetric data with small tails. Both questions (at the pre- and post-test) were intended to utilise the same skills, however the poorer performance accuracy at the post-test suggested that this is, in fact, a subliminal artefact that was introduced when changing the question behaviour between the pre- and post-test i.e., participants may have found it easier to identify the correct box plot at the pre-test due to their ability to recognise skew, whereas participants may have struggled with the symmetric data at the post-test since it did not rely on recognising skew, but instead on identifying tails. Since this question appears to show that the skill types subtly change through the response accuracy rate between the pre- and post-test, we argued to remove S10 for this reason.

This left S12 and S13, of which exactly one had to be rejected. Since both questions showed some improvement between the pre- and post-test, we opted to make an argument based on the questions types themselves. Both S12 and S13 ask about linear regression models of bivariate data, however S12 involves realising the equation of the given regression line, whereas S13 involves interpreting the meaning of the given regression line equation. For question S12 it is not necessary to understand the context of the data in order to answer the question. On the other hand, S13 assesses a participants ability to understand the meaning of the regression line which

Table 6.2 | The selected numeracy and statistics questions for the 2022-2023 Study.

Question	Difficulty	Skills					Pre-test		Post-test		Median Time (seconds)	
		Alg	Con	Calc	Esti	S R	With Post-16 Mathematics	Without Post-16 Mathematics	With Post-16 Mathematics	Without Post-16 Mathematics	Pre-test	Post-test
N1	Level 1		■	■			80%	56%	72%	30%	96	60
N2	Level 1			■			69%	47%	76%	63%	85	50
N3	Level 1	■					78%	48%	76%	53%	33	34
N5	Level 2		■		■		45%	33%	64%	43%	93	77
N11	Level 2	■					44%	19%	56%	10%	39	42
N12	Level 1		■	■			87%	62%	96%	60%	32	21
N13	Level 2		■		■		65%	56%	84%	60%	79	66
N14	Level 2		■		■		75%	72%	92%	57%	76	66
S1	Level 2			■			44%	25%	80%	63%	43	44
S3	Level 1				■		76%	66%	76%	47%	45	40
S5	Level 1					■	67%	86%	96%	93%	23	19
S6	Level 1					■	71%	77%	64%	43%	41	33
S8	Level 1					■	69%	78%	36%	27%	26	26
S11	Level 2				■	■	40%	33%	76%	33%	55	47
S13	Level 2					■	42%	33%	80%	33%	39	37
S14	Level 2			■			69%	66%	64%	37%	40	36

The numeracy and statistics skills have been abbreviated to *Alg* = Algebra, *Con* = Conversion, *Calc* = Calculation, *Esti* = Estimation, *S R* = Statistical Reasoning. A shaded cell indicates the skills which correspond to each question. Numeracy and statistics questions are labelled with the prefix *N* and *S*, respectively. The respective difficulty of each question is either *Level 1* being an easier standard which all participants should be able to access, or *Level 2* being a harder standard which is more accessible to participants with a post-16 mathematics qualification. The accuracy percentages were calculated as the mean number of participants in each group that got the correct answer on the question in the 2021-2022 Study. Also shown are the median times in seconds based on the metadata collected in the 2021-2022 Study.

slightly better aligns with statistical skills than S12. As such, S13 was chosen to be included in the subset of questions and S12 was rejected. This achieved eight numeracy questions and eight statistics questions which are shown in Table 6.2.

6.2.2 Study Participants

Lab-based study

The experiment recruited 132 first-year undergraduate students from 17 departments at the University of Essex. Participants were recruited primarily through the use of flyers and advertisements given at the start or end of lectures by the lead researcher. Participants were asked to scan a QR code which would take them to a sign-up form where a list of available lab sessions were presented to them. Once participants had selected a lab time, they were automatically emailed a booking confirmation which was followed by an email reminder on the day of the lab with details of the time and lab location. Participants were also given instructions on how to change the lab for an alternative date or time if they could no longer attend the lab which they had booked.

Participants who had successfully completed the survey at the pre-test were invited back to complete the post-test once it had reopened in the second term. Participants were contacted using the university email which they had provided at the pre-test with a similar booking form process as the pre-test to sign up for the available lab sessions. Participants were also reminded that they could receive another £10 Amazon voucher as a further incentive to complete the post-test. The demographic characteristics of the lab-based study population at the pre-test and the post-test are shown in Table 6.4.

We also detail the particular mathematics qualifications detailed by participants who stated that they studied mathematics between the ages of 16-18 in Table 6.3.

Online study

The experiment recruited 117 first-year undergraduate students from eight UK universities. Approximately 40 university departments were initially contacted determined by the fact they were

Table 6.3 | Frequencies of participants who had studied post-16 mathematics qualifications for the lab-based study.

Post-16 Mathematics Qualification	**Pre-test**	**Post-test**
Core Mathematics	6	0
AS-Level Mathematics	10	7
A-Level Mathematics	25	14
AS-Level Further Mathematics	2	1
A-Level Further Mathematics	4	3
AS-Level Statistics	3	1
A-Level Statistics	4	2
IB Mathematics Studies SL	0	0
IB Mathematics SL	0	0
IB Mathematics HL	0	0
IB Further Mathematics HL	0	0
Other UK Qualification	0	0
Non-UK Qualification	34	17

IB = International Baccalaureate, *SL* = Standard Level, *HL* = Higher Level. Note that this list does not represent unique numbers of participants since it was possible for participants to have taken more than one post-16 mathematics qualification.

likely to teach modules with quantitative skills in the first year. These contacts were given a short description of the survey aims accompanied with a web link to the survey which was asked to be distributed to first-year undergraduate students in their respective department. Of these initial communications, 14 of these departments resulted in complete responses from their students.

Participants who had successfully completed the survey at the pre-test were invited back to complete the post-test by emailing these participants. We used a unique link for each participant at the post-test and sent weekly reminder emails to participants who had not yet engaged with this link.

Table 6.4 | The demographic characteristics of the study population for the lab-based study.

	Department	Gender				Age		Post-16 Study		Post-16 Maths		Foundation Year	
		Female	Male	Other	Total	Md	(SD)	UK	Non-UK	With	Without	Yes	No
Pre-test	Biology	11	10	0	21	19	(5.0)	15	6	10	11	15	6
	Business	2	4	0	6	20	(1.4)	5	1	2	4	1	5
	CSEE	3	16	0	19	18	(1.4)	14	5	13	6	9	10
	Economics	4	6	0	10	20	(2.0)	9	1	8	2	5	5
	Edge Hotel	1	3	0	4	19	(1.9)	1	3	3	1	2	2
	Film	2	0	0	2	22	(0.7)	1	1	0	2	0	2
	Government	1	0	0	1	20	–	0	1	0	1	1	0
	History	0	1	0	1	18	–	1	0	1	0	0	1
	HSC	1	0	0	1	18	–	1	0	0	1	0	1
	Language	2	0	0	2	19	(1.4)	1	1	2	0	0	2
	Law	0	1	1	2	18	(0.0)	2	0	1	1	2	0
	Maths	5	10	0	15	22	(7.1)	5	10	12	3	3	12
	Pathways	4	2	0	6	18	(4.7)	6	0	1	5	6	0
	Psychology	6	2	3	11	19	(1.5)	9	2	3	8	2	9
	Sociology	15	1	1	17	19	(1.9)	12	5	7	10	0	17
	SRES	3	3	0	6	19	(2.7)	4	2	2	4	2	4
	UEIC	3	4	1	8	18	(6.1)	1	7	7	1	4	4
	Total	**63**	**63**	**6**	**132**	**19**	**(4.1)**	**87**	**45**	**72**	**60**	**52**	**80**
Post-test	Biology	5	2	0	7	19	(6.5)	4	3	5	2	2	5
	Business	0	1	0	1	20	–	1	0	0	1	0	1
	CSEE	1	7	0	8	18	(1.4)	8	0	6	2	4	4
	Economics	2	1	0	3	20	(3.1)	3	0	3	0	2	1
	Edge Hotel	0	2	0	2	20	(0.7)	0	2	2	0	1	1
	Film	2	0	0	2	24	(0.7)	1	1	0	2	0	2
	Government	–	–	–	–	–	–	–	–	–	–	–	–
	History	–	–	–	–	–	–	–	–	–	–	–	–
	HSC	–	–	–	–	–	–	–	–	–	–	–	–
	Language	1	0	0	1	20	–	1	0	1	0	0	1
	Law	0	0	1	1	19	–	1	0	0	1	1	0
	Maths	5	8	0	13	23	(7.2)	4	9	10	3	3	10
	Pathways	3	1	0	4	19	(1.3)	4	0	0	4	4	0
	Psychology	1	1	3	5	18	(0.5)	4	1	0	5	0	5
	Sociology	8	0	0	8	19	(2.7)	5	3	3	5	0	8
	SRES	3	0	0	3	19	(3.5)	1	2	2	1	1	2
	UEIC	2	1	0	3	19	(1.0)	1	2	3	0	1	2
	Total	**33**	**24**	**4**	**61**	**19**	**(4.4)**	**38**	**23**	**35**	**26**	**19**	**42**

Note: Data about a participant's age was collected at both the pre-test and the post-test: *Md* = median; *SD* = standard deviation. Participants from the departments Government, History and HSC completed the study at the pre-test but did not complete the study at the post-test. *Biology* = School of Life Sciences, *Business* = Essex Business School, *CSEE* = School of Computer Science and Electrical Engineering, *Economics* = Department of Economics, *Edge Hotel* = Edge Hotel School, *Film* = Department of Literature, Film and Theatre Studies, *Government* = Department of Government, *History* = Department of History, *HSC* = School of Health and Social Care, *Language* = Department of Language and Linguistics, *Law* = Essex Law School, *Maths* = Department of Mathematical Sciences, *Pathways* = Essex Pathways Department, *Psychology* = Department of Psychology, *Sociology* = Department of Sociology, *SRES* = School of Sport, Rehabilitation and Exercise Science, *UEIC* = University of Essex International College.

Table 6.5 | The demographic characteristics of the study population for the online study.

	University	**Gender**				**Age**		**Post-16 Study**		**Post-16 Maths**		**Foundation Year**	
		Female	Male	Other	Total	Md	(SD)	UK	Non-UK	With	Without	Yes	No
	Bournemouth	0	1	0	1	19	–	1	0	0	1	0	1
	Cambridge	3	1	0	4	18	(0.0)	4	0	4	0	0	4
	Cardiff	10	9	1	20	18	(0.6)	18	2	13	7	1	19
	Edinburgh	1	0	0	1	19	–	1	0	0	1	0	1
	Hertfordshire	1	1	0	2	20	(1.4)	1	1	2	0	0	2
	Newcastle	7	6	0	13	18	(0.5)	13	0	13	0	3	10
	Northumbria	0	1	0	1	19	–	1	0	0	1	1	0
Pre-test	Portsmouth	18	6	0	24	20	(1.3)	21	3	13	11	5	19
	Queen Mary	1	0	0	1	20	–	1	0	0	1	0	1
	Royal Holloway	0	1	0	1	18	–	1	0	1	0	0	1
	Surrey	1	1	0	2	18	(0.7)	2	0	2	0	0	2
	UEA	8	14	1	23	19	(4.9)	20	3	12	11	7	16
	Warwick	2	6	0	8	18	(1.2)	8	0	8	0	0	8
	York	9	5	1	15	18	(0.9)	14	1	15	0	0	15
	Total	**61**	**52**	**3**	**116**	**18**	**(2.5)**	**106**	**10**	**83**	**33**	**17**	**99**
	Bournemouth	–	–	–	–	–	–	–	–	–	–	–	–
	Cambridge	2	1	0	3	18	(0.6)	3	0	3	0	0	3
	Cardiff	8	7	1	16	18	(0.8)	14	2	11	5	1	15
	Edinburgh	–	–	–	–	–	–	–	–	–	–	–	–
	Hertfordshire	0	1	0	1	21	–	0	1	1	0	0	1
	Newcastle	4	6	0	10	19	(2.7)	10	0	10	0	1	9
	Northumbria	0	1	0	1	19	–	1	0	0	1	1	0
Post-test	Portsmouth	15	5	0	20	20	(1.4)	17	3	13	7	5	15
	Queen Mary	1	0	0	1	20	–	1	0	0	1	0	1
	Royal Holloway	0	1	0	1	19	–	1	0	1	0	0	1
	Surrey	1	1	0	2	18	(0.7)	2	0	2	0	0	2
	UEA	7	14	1	22	19	(4.9)	20	2	11	11	7	15
	Warwick	2	5	0	7	19	(0.8)	7	0	7	0	0	7
	York	8	5	1	14	19	(0.6)	13	1	14	0	0	14
	Total	**48**	**47**	**3**	**98**	**19**	**(2.6)**	**89**	**9**	**73**	**25**	**15**	**83**

Note: Data about a participant's age was collected at both the pre-test and the post-test: *Md* = median; *SD* = standard deviation. Participants from the universities Bournemouth and Edinburgh completed the study at the pre-test but did not complete the study at the post-test. *Bournemouth* = Bournemouth University, *Cambridge* = University of Cambridge, *Cardiff* = Cardiff University, *Edinburgh* = University of Edinburgh, *Hertfordshire* = University of Herfordshire, *Newcastle* = Newcastle University, *Northumbria* = Northumbria University, *Portsmouth* = University of Portsmouth, *Queen Mary* = Queen Mary University of London, *Royal Holloway* = Royal Holloway University of London, *Surrey* = University of Surrey, *UEA* = University of East Anglia, *Warwick* = University of Warwick, *York* = University of York.

Table 6.6 | The degrees taken by participants in the online study.

	Pre-test	Post-test
Astrophysics	1	1
Banking and finance	5	4
Biochemistry	8	7
Biology	12	12
Biomedicine	12	11
Business economics	2	2
Childhood and youth studies with psychology	1	1
Computer science	4	3
Computer science and mathematics	1	1
Computer systems engineering	2	2
Ecology and conservation	1	1
Economics	4	5
Economics and finance	2	2
Economics and French	1	0
Economics and management studies	3	2
Economics with finance	3	0
English language and linguistics	1	1
Financial mathematics	1	0
French and Spanish	1	1
German and economics	1	1
Graphic design	1	1
Illustration	1	0
Marine biology	10	6
Mathematics	23	22
Mathematics and computer science	1	1
Mathematics and economics	2	1
Mathematics and physics	3	3
Mathematics and statistics	1	0
Mechanical engineering	1	1
Microbiology	1	0
Natural sciences	1	1
Pharmacology	1	1
Physics	1	1
Psychology and mathematics	2	2
Social sciences	1	1

The demographic characteristics of the online study population at the pre-test and the post-test are shown in Table 6.5 and the degree courses that they were studying are shown in Table 6.6. One of the demographic questions at the start of the survey was a free text input box which established the degree scheme that participants in this study were enrolled on. Based on these responses, we estimated that 96% of participants in this study who completed both the pre-test and the post-test were studying a quantitative module in their first term of university.

We also detail the particular mathematics qualifications detailed by participants who stated that they studied mathematics between the ages of 16-18 in Table 6.7.

Table 6.7 | Frequencies of participants who had studied post-16 mathematics qualifications for the online-based study.

Post-16 Mathematics Qualification	Pre-test	Post-test
Core Mathematics	2	2
AS-Level Mathematics	21	15
A-Level Mathematics	68	59
AS-Level Further Mathematics	18	13
A-Level Further Mathematics	26	23
AS-Level Statistics	5	3
A-Level Statistics	5	3
IB Mathematics Studies SL	0	0
IB Mathematics SL	0	0
IB Mathematics HL	1	1
IB Further Mathematics HL	0	0
Other UK Qualification	0	0
Non-UK Qualification	8	7

IB = International Baccalaureate, *SL* = Standard Level, *HL* = Higher Level. Note that this list does not represent unique numbers of participants since it was possible for participants to have taken more than one post-16 mathematics qualification.

6.2.3 Study Materials

Numeracy test

Participants were given a set of eight numeracy questions at the pre-test and eight numeracy questions at the post-test. The questions were altered between the pre-test and the post-test so that the question skills remained similar, however the context and numeric values were changed to overcome learning effects between each round of testing. For each question, participants were given a set of four multiple-choice options with only one option being correct. The question order and the order of the multiple-choice options were randomised. The questions covered four skill areas: calculation; conversions; estimation; algebra. In order to ensure that all participants could reasonably be expected to attempt all items, questions were designed to utilise knowledge from topic areas up to and including GCSE Mathematics. They were divided into two equal groups according to the level of difficulty: four questions which all participants would be expected to answer correctly; four questions which participants with post-16 mathematics were more likely to answer correctly. Participants were instructed not to use a calculator and advised to spend approximately one minute answering each question prior to starting the numeracy test. Plain paper was provided on their desks for any rough working and participants were provided with pens on request. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the eight items for overall scores. Question metadata such as the time taken to first select an answer, time taken to select their last answer, time taken to submit the page, and number of answers selected prior to submitting their response was also recorded, but this data was not shown to participants.

Statistics test

As in the numeracy test, participants were given a set of eight statistics questions at the pre-test and eight statistics questions at the post-test. Questions were altered between the pre-test and post-test in the same way as the numeracy test with the question skills remaining similar, however question context and numeric values were changed. Each question had four possible multiple-choice options with only one option being correct. Question order and the order of the multiple-choice options were randomised. The questions covered three skill areas: estimation; calculation; statistical reasoning. Similar rationale to the numeracy test was applied for the design of the statistics test, with questions utilising knowledge from topic areas up to and including GCSE Mathematics. They were divided into two equal groups according to the level of difficulty: four questions which all participants would be expected to answer correctly; four questions which participants with post-16 mathematics were more likely to answer correctly. To ensure consistency with the procedure for the numeracy questions, participants were given the same instructions and advice regarding not using a calculator and expected time per question and given pen and paper materials for rough working. The responses, coded as *correct* (numeric value of 1) or *incorrect* (numeric value of 0), were summed across the eight items for overall scores. The same question metadata as the numeracy questions was also collected.

Confidence judgments

After each numeracy and statistics question, participants were asked, “How confident are you that you gave the correct answer in the previous question?” and had to rate their confidence according to a four-point Likert scale (1 = *I am guessing*, 2 = *I am not confident*, 3 = *I am quite confident*, 4 = *I am very confident*). An overall confidence score for both the numeracy and statistics questions was calculated by averaging all confidence ratings. Additional accuracy scores for the numeracy and statistics questions were calculated by coding each question as accurate (numeric value of 1: either high confidence and question correct, or low confidence and question incorrect) or inaccurate (numeric value of 0: either low confidence and question correct, or high confidence and question incorrect). These scores were then averaged to obtain overall accuracy scores for the statistics questions and for the numeracy questions which corresponded to the proportion of accurate judgments for each test. The thresholds for *high confidence* (confidence rating of 3 or 4) and *low confidence* (confidence rating of 1 or 2) were chosen based on the descriptions of the Likert scale that was shown to participants. Figure 6.1 shows the confidence scale which was asked after each of the numeracy and statistics questions.

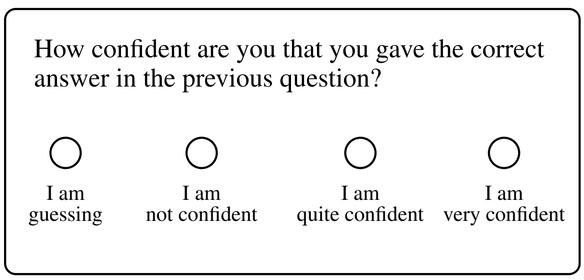


Figure 6.1 | The confidence scale which was asked after each of the numeracy and statistics questions.

Numeracy ability and preference

Since we had reduced the number of questions in our numeracy and statistics test, we used the Subjective Numeracy Scale (SNS, Fagerlin et al., 2007) as a means of validation. The eight-item questionnaire consists of a four-item numerical ability subscale and a four-item numerical preference subscale. The questionnaire contains no correct or incorrect answers and instead, asks respondents to consider everyday scenarios and state their perceived ability or preference with the given scenario. For example, the numerical ability subscale asks participants to assess their numerical ability in different contexts (e.g., *How good are you at working with percentages?*) on a six-point Likert scale (1 = *not at all good*, 6 = *extremely good*); the numerical preference subscale asks participants to consider their preferred method for the presentation of numerical and probabilistic information (e.g., *When people tell you the chance of something happening, do you prefer that they use words ("it rarely happens") or numbers (there is a 1% chance)?*) on a six-point Likert scale (e.g., 1 = *always prefer words*, 6 = *always prefer numbers*). An overall score between 1 (low numerate) and 6 (highly numerate) is obtained by taking the mean average of all ratings. Two further scores are obtained in an similar way for the numerical ability and numerical preference subscales. The internal consistency (Cronbach's alpha) for the SNS in the lab-based study was $\alpha = 0.823$ (pre-test) and $\alpha = 0.795$ (post-test), and for the online study was $\alpha = 0.756$ (pre-test) and $\alpha = 0.771$ (post-test) which is comparable to the reported $\alpha = 0.807$ by the authors.

Mathematics anxiety

Data about a participant's mathematics anxiety was collected using the Adult Everyday Mathematics Anxiety Scale (AEMAS, Rolison et al., 2016). The 13-item questionnaire asked participants to rate how anxious they would feel during the event specified (e.g., *Figuring how much a shirt will cost if it is 25% off*) on a five-point Likert scale (1 = *low anxiety*, 2 = *some anxiety*, 3 = *moderate anxiety*, 4 = *quite a bit of anxiety*, 5 = *high anxiety*). An overall mathematics anxiety score was obtained by calculating the mean average of all 13 ratings. The internal consistency (Cronbach's alpha) for the lab-based study was $\alpha = 0.901$ (pre-test) and $\alpha = 0.922$ (post-test), and for the online study was $\alpha = 0.913$ (pre-test) and $\alpha = 0.898$ (post-test) which is comparable to the α = 0.93 reported by the authors.

Personality traits

Data was collected about participants' personality traits using the Big Five Inventory 2 Short (BFI-2-S, Soto & John, 2017b). This 30-item questionnaire is an abbreviated version of the 60-item BFI-2 which we used in the 2019-2020 Study. Since we were using more instruments in this study than in either the 2019-2020 Study or the 2021-2022 Study as well as conducting a part of this study online, we considered that participant boredom or fatigue was a vital concern that we needed to address in order to limit incomplete attempts. We believed that this necessitated a shorter form of the BFI-2. In such cases, the authors claim that the BFI-2-S still retains a good level of reliability when assessing the broad Big Five domains when compared with the BFI-2. Similar to the full version, the BFI-2-S consists of short, descriptive phrases which participants were asked to rate their agreement with on a five-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*). Items completed the sentence stem "I am someone who..." and measured each of the five personality traits (openness, conscientiousness, extraversion, agreeableness, neuroticism) using six items per trait. The scores for each personality trait were calculated by reverse coding specific items and then taking the mean average to obtain a value for each of trait which ranged from 1 (low in this trait) to 5 (high in this trait). Table 6.8 compares the reliability of our study to the US version of (Soto & John, 2017b).

Table 6.8 | Comparing the reliability of the BFI-2-S personality instrument for our study and the US version from Soto & John (2017b).

Trait	Lab-based Study	Online Study	US Version
Openness	α = 0.592	α = 0.624	α = 0.77
Conscientiousness	α = 0.704	α = 0.616	α = 0.73
Extraversion	α = 0.744	α = 0.792	α = 0.78
Agreeableness	α = 0.704	α = 0.767	α = 0.75
Neuroticism	α = 0.776	α = 0.864	α = 0.82

Attitudes towards mathematics

The Short Attitudes Toward Mathematics Inventory (Short ATMI, Lim & Chapman, 2013) is an abbreviated version of the full Attitudes Toward Mathematics Inventory by Tapia & Marsh (2004). The Short ATMI consists of 19 statements consisting of four subscales regarding a participant's attitudes towards mathematics:

Enjoyment (five-items) – e.g., *I like to solve new problems in mathematics.*

Motivation (four-items) – e.g., *The challenge of mathematics appeals to me.*

Sense of Security (five-items) – e.g., *Studying mathematics makes me feel nervous.*

Value (five-items) – e.g., *Mathematics is important in everyday life.*

Participants were asked to rate their agreement with each of the given statements using a five-point Likert scale (1 = *disagree strongly*, 2 = *disagree a little*, 3 = *neutral; no opinion*, 4 = *agree a little*, 5 = *agree strongly*). A score for each of the four subscales was obtained by calculating the sum of all ratings. Whilst the authors of the Short ATMI suggested that removal of the motivation subscale may lead to higher overall reliability, we elected to administer the complete 19-item inventory. Table 6.9 shows the internal consistencies (Conbach's alphas) of our instrument compared with that of the authors.

Table 6.9 | Comparing the reliability of the Short ATMI instrument for our study and the version from Lim & Chapman (2013).

Subscale	**Lab-based Study**		**Online Study**		**Author Version**
	Pre-test	Post-test	Pre-test	Post-test	
Enjoyment	$\alpha = 0.924$	$\alpha = 0.933$	$\alpha = 0.922$	$\alpha = 0.919$	$\alpha = 0.90$
Motivation	$\alpha = 0.889$	$\alpha = 0.888$	$\alpha = 0.893$	$\alpha = 0.906$	$\alpha = 0.85$
Sense of Security	$\alpha = 0.908$	$\alpha = 0.918$	$\alpha = 0.883$	$\alpha = 0.864$	$\alpha = 0.94$
Value	$\alpha = 0.863$	$\alpha = 0.795$	$\alpha = 0.795$	$\alpha = 0.842$	$\alpha = 0.90$

Note: The authors reported on the internal consistencies for each of the subscales from two subsamples ($N = 800$ and $N = 801$). Since the α values varied by 0.01 at most between each subsample, we have chosen to reported the lower of the two Cronbach's Alphas for the author version here.

COVID-19

We devised a short questionnaire to determine whether a participant perceived that COVID-19 had impacted their education. Firstly, participants were given a question to determine whether they were in education during March 2020 and August 2022 (*yes*, *no*). We then established where that education took place for each of the three academic years during this period (*in a classroom*, *online*, *hybrid*, *no lessons*). For participants who answered positively to these questions, they were subsequently given four statements which corresponded to the impact of COVID-19 on education (e.g., *COVID-19 has meant that I have had to change the methods that I use to learn and study*) and were asked to rate their agreement on a five-point Likert scale (*1 = strongly disagree*, *5 = strongly agree*). An alternative four statements were given at the post-test which corresponded to the transition to university (e.g., *I feel that the disruption which COVID-19 has caused to my learning since March 2020 made the transition to university harder*) and the same five-point Likert scale was used.

6.2.4 Study Procedure

Lab-based study

The pre-test was open in the autumn term from 7th October 2022 to 13th November 2023 in order to ensure that participants would be exposed to a maximum of five weeks of university teaching. The post-test was open in the spring term from 16th January 2023 to 19th February 2023 which equates to the same amount of term time as the pre-test. Lab sessions were booked daily from Monday to Saturday and participants were given the option to attend a 50-minute period starting on the hour. At least two lab periods were available per day and varied in their times in order to provide a wide range of choice for participants.

When participants arrived at the lab, the lead researcher would ask them to confirm that they were first-year undergraduate students before escorting them to an available computer. Where possible, participants were positioned at computers which limited the possibility of being able to view another participant's screen. Participants were given a page of pre-printed instructions which reminded them of the expectations of the lab as well as how to access the survey. They were also given a single sheet of plain A4 paper and a pen to be used for workings during the numeracy and statistics tests. Participants independently followed the instructions on the pre-printed instruction sheet and logged in using their university intranet credentials to open a web browser. The lead researcher closely monitored the participants in the early stages to ensure that they were following the instructions correctly as well as to answer questions which they may have. The lead researcher then periodically circulated the room to ensure that participants were positively engaging in the survey according to the lab instructions.

The experiment was programmed using the online survey platform Qualtrics. Participants were instructed to type the bit.ly link that was located on the pre-printed instruction sheet in order to access the survey. The first pages of the survey provided participants with a brief overview of the study aims. This included a hyperlink to the participant information sheet which was optional for participants to read. This was then followed with a set of check-boxes where participants provided informed consent.

At the pre-test, it was necessary to collect an email address in order for the lead researcher to: firstly, contact participants for the post-test; secondly, send the £10 Amazon voucher payment; and thirdly, recode this to a participant number that would act as a unique identifier between the pre-test and the post-test for the purposes of data analysis. As such, a typed response box was provided in the opening pages of the survey for participants to enter their university email address. A validation check was applied to this to ensure that the email address that was entered conformed to the expected format of a university address. If not, participants were prompted to reenter this in the correct format before they could proceed. Participants were informed of the purpose of providing their university email address in the on-screen instructions.

Once a participant had completed the survey, they were shown an on-screen unique completion code which was automatically generated by Qualtrics. Participants were instructed to make a record of this code and bring it to the lead researcher in the room who would use the code to verify that they had indeed completed all questions in the survey and that their responses had been successfully recorded. The lead researcher would then ensure that these participants were emailed the £10 Amazon voucher code within five working days of completing the survey.

After the pre-test was closed, each email address was recoded as a unique participant number. This was emailed to participants upon booking for the post-test and was also given by the lead researcher to each participant upon entering the post-test labs. Participants were asked to enter this participant number in a typed response box at the post-test.

Online study

The online version of the experiment used identical questions in the same order as the lab-based version, apart from the numeracy and statistics tests which remained randomised in order to prevent participants from working together. Participants were sent a link to the survey which they could choose to complete at a time convenient to them. We also delayed the collection of data by five days until we had started the data collection of the lab-based study in order to ensure that there were no errors with Qualtrics. As such, the pre-test was open between 12th October 2023 and 13th November 2023 and the post-test was open between 21st January 2023 and 19th February 2023.

Consent was obtained in an identical way to the lab-based study. Some demographic questions were adapted to be suitable for participants from different universities such as requesting participants to state the name of their university as well as their department and degree scheme. Participants were also instructed that they had to complete the survey in a time between 10 minutes and 90 minutes in order to receive the £10 Amazon voucher. This was to encourage participants to take the survey in a single session and reduce the ability to seek assistance in answering the questions. The minimum time limit was intended to prevent participants from rapidly selecting answers without positively engaging with the survey.

At the post-test, the lead researcher emailed a unique survey link to each of the participants who had completed the pre-test. Whilst this was sufficient to be able to match participants' responses from the pre-test to the post-test, we also requested that participants entered their university email address again as a form of validation. Reminder emails were then sent at the start of each week until the survey closed to participants who had not yet engaged with the survey at the post-test.

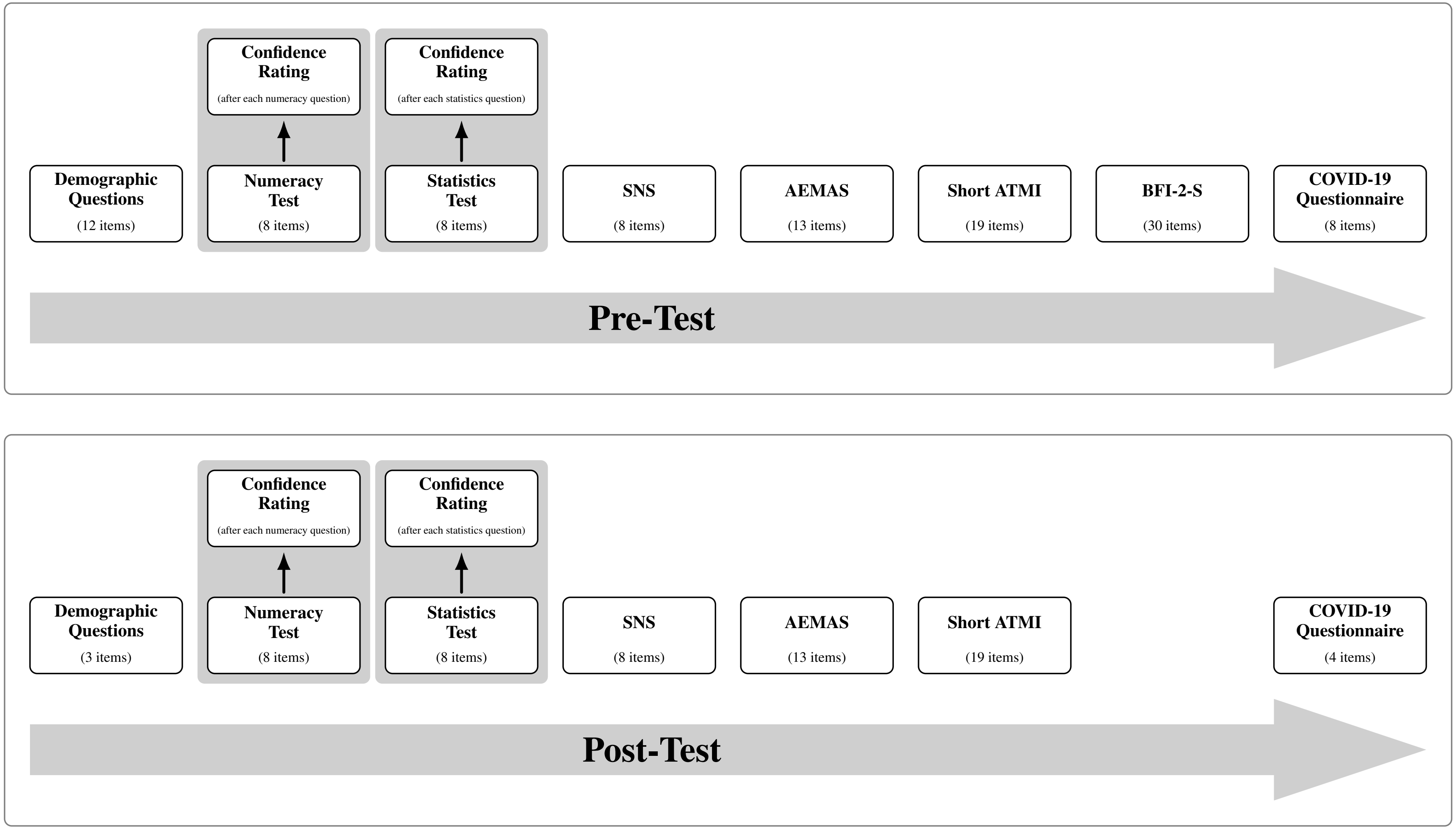


Figure 6.2 | The course of the experiment at the pre-test and the post-test. Also shown is an example numeracy question with multiple-choice options and its subsequent confidence rating with a slider. *SNS* = Subjective Numeracy Scale; *AEMAS* = Adult Everyday Mathematics Anxiety Scale; *Short ATMI* = Short Attitudes Towards Mathematics Inventory; *BFI-2-S* = Big Five Inventory 2 Short.

6.2.5 The Course of the Experiment

The experiment started with a short demographic questionnaire followed by the numeracy test, the statistics test, the Subjective Numeracy Scale (SNS), the Adult Everyday Mathematics Anxiety Scale (AEMAS), the Short Attitudes Towards Mathematics (Short ATMI), the Big Five Inventory 2 Short (BFI-2-S) and the COVID-19 questionnaire. After each of the questions in the numeracy and statistics test, participants were asked to rate their confidence in the correctness of their answer in the previous question. Figure 6.2 displays the course of the experiment for the pre-test and the post-test. The BFI-2-S was used at the pre-test only, since the evidence shows that personality traits are expected to remain relatively stable, particularly for the time period between the pre-test and the post-test (Bleidorn et al., 2019; McCrae & Costa, 1995).

6.2.6 Sample Size Calculations

Lab-based Study

We investigated whether the sample size for the lab-based study possessed enough statistical power to assess differences between the groups. 61 participants completed both the pre-test and the post-test, where 35 of those participants had a post-16 mathematics qualification and 26 participants did not. Considering two independent sample *t*-tests for 13 primary hypotheses which were Bonferroni corrected to give a significance level of $\frac{5\%}{13} = 0.38\%$ and using a standard deviation of 0.125 and a desired statistical power of 80%, we found that the sample size was powered enough to detect differences in accuracy as small as 13.5%.

Online Study

We investigated whether the sample size possessed enough statistical power to assess differences between the groups. For the online study, 98 participants completed both the pre-test and the post-test, where 73 of those participants had a post-16 mathematics qualification and 25 participants did not. Considering two independent sample *t*-tests for 13 primary hypotheses which were Bonferroni corrected to give a significance level of $\frac{5\%}{13} = 0.38\%$ and using a standard deviation of 0.125 and a desired statistical power of 80%, we found that the sample size was powered enough to detect differences in accuracy as small as 13.8%.

6.2.7 Statistical Analysis

This study was pre-registered and so the main analysis followed the data analysis listed for the 13 hypotheses as given by Partner et al. (2022). We also formed path analysis models and explored additional relationships as exploratory analysis.

We tested for the assumption of normality in the data using a Shapiro-Wilk test on the groups of participants with and without a post-16 mathematics qualification for each data set.

Lab-based study data: Whilst most of these tests showed sufficient evidence to reject the null hypothesis in favour of the assumption that the lab-based data is normally distributed, we also visually inspected their histograms as well as measuring their skewness and kurtosis (Table 6.10). Most histograms had a skewness value between -0.5 and 0.5 which implied that they were approximately symmetric, however some had kurtosis values which were close to 2. Using the reference that a normal distribution should have kurtosis of 3, we implied that the majority of these histograms were platykurtic and thus had fewer extreme values. Whilst a statistical transformation of the data may have allowed us to use parametric techniques, we instead chose to proceed with a more robust approach of non-parametric analysis. As such, the main analysis consisted of Wilcoxon signed-rank tests to determine differences between groups and Spearman rank-order correlation tests to determine correlations between variables. For the Wilcoxon signed-rank tests we report the test statistic W, the Bonferroni-adjusted p-value, the 95% confidence interval based on the scale of individuals, and the Cohen's d effect size. For the Spearman rank-order correlation tests we report the test statistic S, the Bonferroni-adjusted p-value, and the correlation coefficient ρ.

Online study data: Most of the variables which were to be used in the primary analysis were found not to be normally distributed which we further verified using visual inspection of their histograms and measuring skewness and kurtosis (Table 6.11). Whilst a statistical transformation of the data may have allowed us to use parametric techniques, we instead chose to proceed with a more robust approach of non-parametric analysis. As such, the main analysis consisted of

Table 6.10 | **Lab-based data:** Testing the normality assumptions for the variables performance accuracy, retrospective confidence judgments and mathematics anxiety for the groups with and without a post-16 mathematics qualification at the pre- and post-test.

		Post-16 Maths	W	**p-value**	**Skewness**	**Kurtosis**
Pre-test	**Performance accuracy**	With	0.9595	0.0207	0.196	2.064
		Without	0.9703	0.1505	0.144	2.420
	Confidence	With	0.9715	0.1017	-0.411	2.551
		Without	0.9827	0.5533	-0.113	2.493
	Maths Anxiety	With	0.9694	0.0768	0.517	3.454
		Without	0.9832	0.5759	-0.191	2.482
Post-test	**Performance accuracy**	With	0.9639	0.2992	-0.060	2.119
		Without	0.9717	0.6667	-0.068	2.373
	Confidence	With	0.9608	0.2412	-0.441	2.571
		Without	0.9798	0.8705	-0.376	2.890
	Maths Anxiety	With	0.9611	0.2464	0.048	2.037
		Without	0.9729	0.6991	-0.031	2.818

Wilcoxon signed-rank tests to determine differences between groups and Spearman rank-order correlation tests to determine correlations between variables. For the Wilcoxon signed-rank tests we report the test statistic W, Bonferroni-adjusted p-value, the 95% confidence interval based on the scale of individuals, and the Cohen's d effect size. For the Spearman rank-order correlation tests we report the test statistic S, the Bonferroni-adjusted p-value, and the correlation coefficient ρ.

The exploratory analysis consisted of path analysis models using a combination of demographic and observed scores to predict the numeracy and statistics scores at each of the pre-test, post-test and pre-/post-test (see Section 1.4). Each model was subjected to goodness-of-fit statistics to assess how well the model fit the data, of which we primarily used the Root Mean Square Error

Table 6.11 | **Online data:** Testing the normality assumptions for the variables performance accuracy, retrospective confidence judgments and mathematics anxiety for the groups with and without a post-16 mathematics qualification at the pre- and post-test.

		Post-16 Maths	W	p**-value**	**Skewness**	**Kurtosis**
Pre-test	**Performance accuracy**	With	0.9124	<0.001	-0.985	3.617
		Without	0.9403	0.0694	0.513	2.615
	Confidence	With	0.9730	0.0782	-0.523	2.885
		Without	0.9637	0.3282	-0.240	2.330
	Maths Anxiety	With	0.9264	<0.001	1.099	4.760
		Without	0.9653	0.3620	0.609	3.102
Post-test	**Performance accuracy**	With	0.9001	<0.001	-0.998	3.696
		Without	0.9390	0.1401	-0.176	1.887
	Confidence	With	0.9555	0.0116	-0.696	3.189
		Without	0.9585	0.3861	-0.573	3.512
	Maths Anxiety	With	0.9311	<0.001	0.959	4.526
		Without	0.9132	0.0359	0.988	3.644

of Approximation (RMSEA) and the χ^2 goodness-of-fit indices. We looked for a RMSEA value of less than 0.08 in order to be considered a good fit for the data and, likewise, a non-significant χ^2 value suggested evidence in favour of the null hypothesis that the model fits the data (Hu & Bentler, 1999). To control for effects of sample size on the RMSEA and χ^2 values, we also used additional fit indices of Standardised Root Mean Square Residual (SRMR), Tucker-Lewis Index (TLI) and the Comparative Fit Index (CFI), of which SRMR $<$ 0.08, TLI $>$ 0.95 and CFI > 0.90 were considered as optimal thresholds to indicate that the model fits the data (Hu & Bentler, 1999). To ensure good model fit, we started with a hypothesised model including all variables and used a backwards selection method to remove non-significant variables until we achieved a model with goodness-of-fit indices within the desired ranges.

The data was analysed using the R language and environment for statistical computing and graphics version 4.3.2 (R Core Team, 2023) and the integrated environment R Studio version 2023.12.1+402. We used the R packages: lavaan (Rosseel, 2012); lavaanPlot (Lishinski, 2024); effsize (Torchiano, 2020); moments (Komsta & Novomestky, 2022).

6.3 Results of the Lab-based Study

For brevity and clarity we will refer to Group 1 and Group 2 as:

Group 1: Participants who had studied a post-16 mathematics qualification.

Group 2: Participants who had not studied a post-16 mathematics qualification.

6.3.1 Pre-registered Main Analysis of the Lab-based Study

Hypothesis 1: Performance accuracy in numeracy and statistics tests

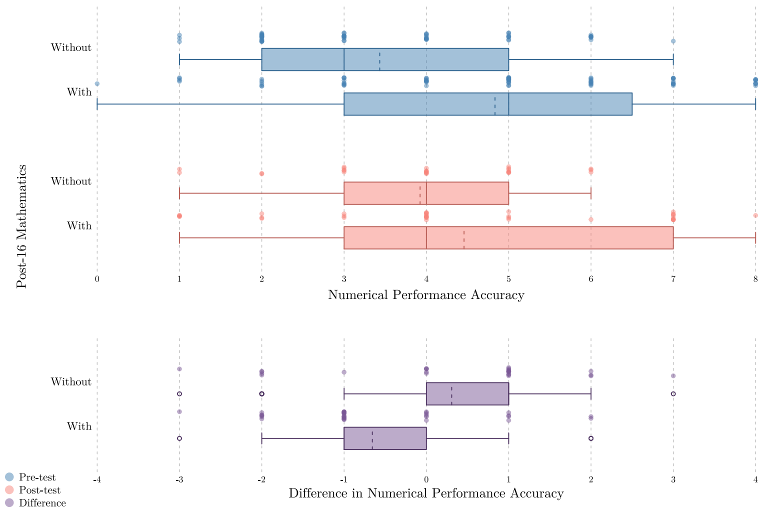
Primary Analysis

Group 1 had higher performance accuracy than Group 2 on the numeracy and statistics tests at the pre-test (Wilcoxon-test: $W = 1420$, $p < 0.001$, $95\%CI = [-3.000, -1.000]$, $d = -0.681$) but not at the post-test (Wilcoxon-test: $W = 345.5$, $p = 0.1099$, $95\%CI = [-3.000, 0.000]$, $d = -0.460$).

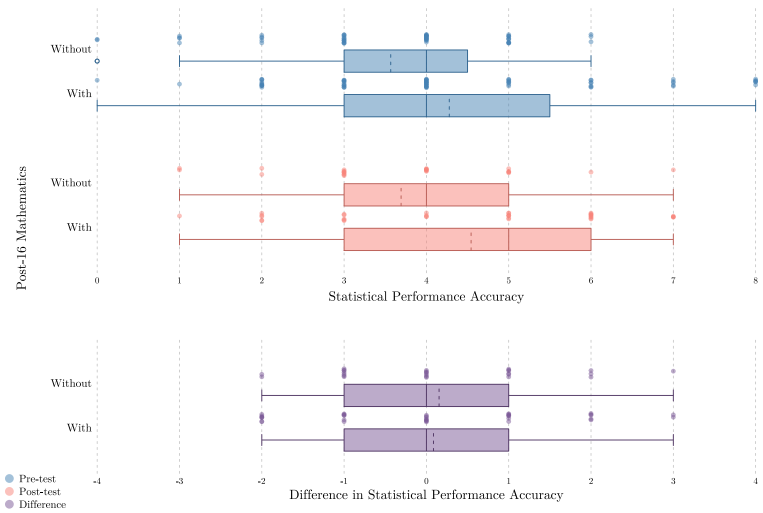
There was not a significant difference in the change in performance accuracy for either group between the pre-test and the post-test (Wilcoxon-test: $W = 612$, $p = 0.2662$, $95\%CI = [0.000, 1.000]$, $d = 0.541$).

Secondary Analysis

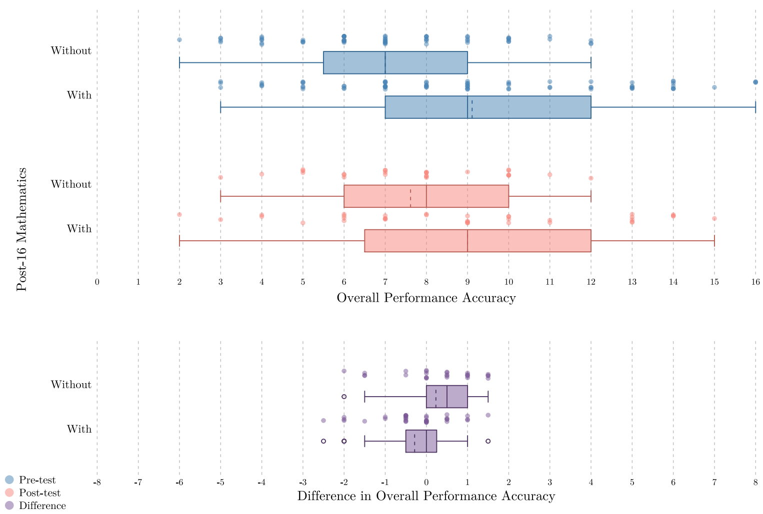
Group 1 were found to have better performance accuracy than Group 2 on the numeracy questions at the pre-test (Wilcoxon-test: $W = 1286$, $p < 0.001$, $95\%CI = [-2.000, -1.000]$, $d = -0.754$) but not at the post-test (Wilcoxon-test: $W = 390$, $p = 1.00$, $95\%CI = [-2.000, 1.000]$, $d = -0.291$). There was no significant difference in performance accuracy found between



(a) Performance accuracy scores on the numeracy tests.



(b) Performance accuracy scores on the statistics tests.



(c) Overall performance accuracy scores.

Figure 6.3 | Boxplots showing the overall performance accuracy scores for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in performance accuracy scores between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

Group 1 and Group 2 on the statistics items at the pre-test (Wilcoxon-test: $W = 1793$, $p = 0.0868$, $95\%CI = [-1.000, 0.000]$, $d = -0.423$) nor at the post-test (Wilcoxon-test: $W = 319$, $p = 1.00$, $95\%CI = [-2.000, 0.000]$, $d = -0.530$).

There were no significant differences found in the changes in performance accuracy for either group between the pre-test and the post-test for the numeracy test (Wilcoxon-test: $W = 639.5$, $p = 0.1435$, $95\%CI = [0.000, 2.000]$, $d = 0.736$) nor for the statistics test (Wilcoxon-test: $W = 468.5$, $p = 0.8466$, $95\%CI = [-1.000, 1.000]$, $d = 0.048$).

Hypothesis 2: Retrospective confidence judgments

Primary Analysis

There was no significant difference in the confidence ratings between Group 1 and Group 2 at the pre-test (Wilcoxon-test: $W = 1570.5$, $p = 0.0920$, $95\%CI = [-0.562, -0.125]$, $d = -0.460$).

There was a significant positive correlation between confidence ratings and performance accuracy at the pre-test (Spearman rank correlation coefficient: $S = 166\,699$, $p < 0.01$, $\rho = 0.565$).

Secondary Analysis

There were no significant differences found between Group 1 and Group 2 and their confidence ratings at the post-test (Wilcoxon-test: $W = 296$, $p = 0.4968$, $95\%CI = [-0.688, -0.063]$, $d = -0.604$). There were also no significant difference found between the groups on the numeracy questions at the pre-test (Wilcoxon-test: $W = 1576$, $p = 0.1814$, $95\%CI = [-0.625, -0.125]$, $d = -0.477$) or the post-test (Wilcoxon-test: $W = 275$, $p = 0.2088$, $95\%CI = [-0.875, -0.125]$, $d = -0.763$), and similarly for the statistics questions at the pre-test (Wilcoxon-test: $W = 160.5$, $p = 0.2760$, $95\%CI = [-0.500, -0.125]$, $d = -0.381$) or the post-test (Wilcoxon-test: $W = 353$, $p = 1.00$, $95\%CI = [-0.625, 0.125]$, $d = -0.338$).

There was a significant positive correlation between confidence and performance accuracy at the post-test (Wilcoxon-test: $S = 17\,537$, $p < 0.001$, $\rho = 0.536$).

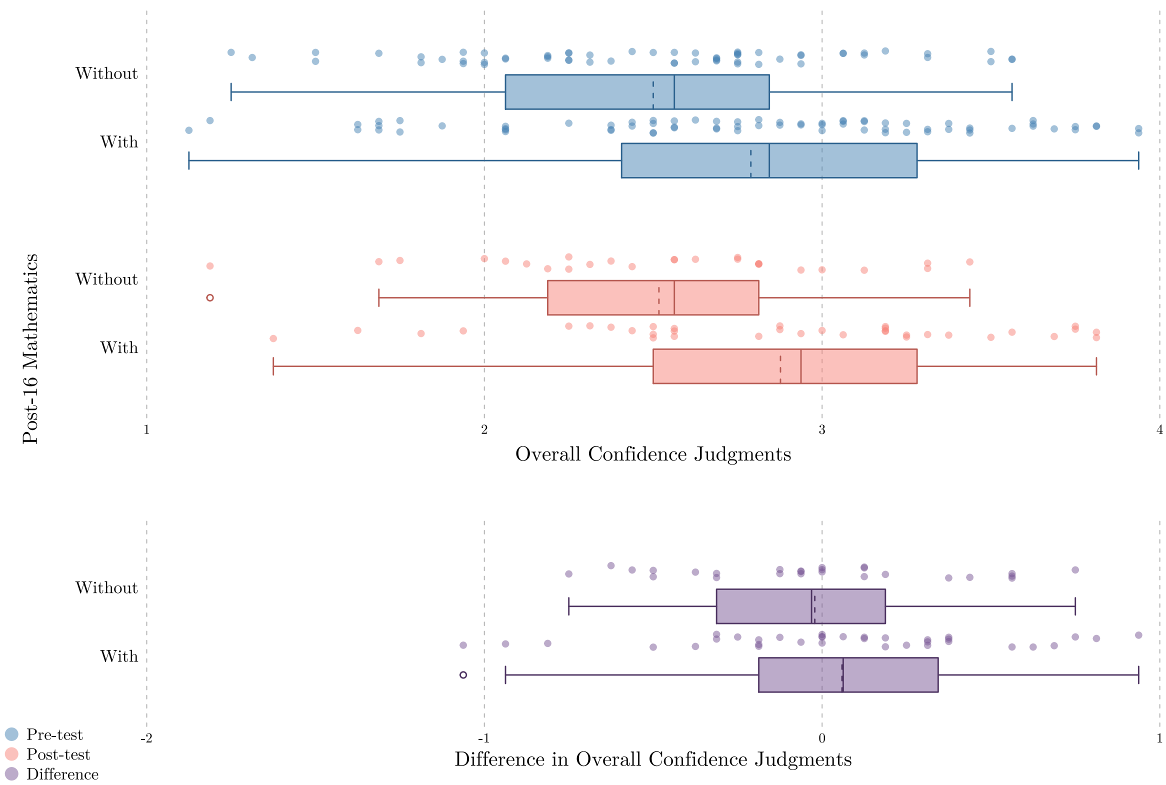


Figure 6.4 | Boxplots showing the overall confidence judgments for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in confidence judgments between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

Hypothesis 3: Mathematics anxiety

Primary Analysis

Group 2 was found to have higher mathematics anxiety than Group 1 at the pre-test (Wilcoxon-test: $W = 3025$, $p < 0.01$, $95\%CI = [0.308, 0.923]$, $d = 0.711$).

There was a significant negative correlation between performance accuracy and mathematics anxiety levels at the pre-test (Spearman rank correlation coefficient: $S = 492\,495$, $p = 0.0121$, $\rho = -0.285$). There was also a significant negative correlation between confidence ratings and mathematics anxiety levels at the pre-test (Spearman rank correlation coefficient: $S = 545\,361$, $p < 0.001$, $\rho = -0.423$).

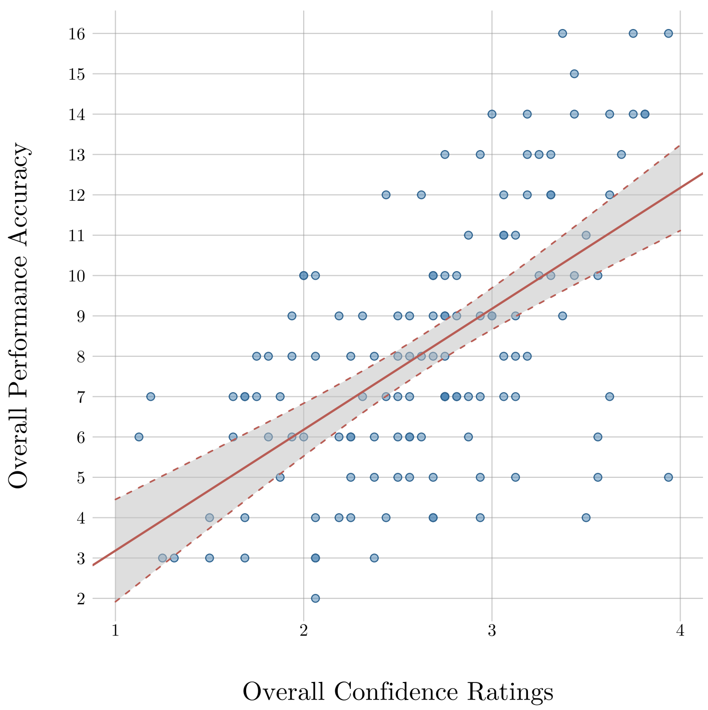


Figure 6.5 | Scatterplot showing the statistically significant correlation between the performance accuracy scores and the confidence judgments at the pre-test. This plot also shows a simple linear regression model $\hat{y} = 0.19 + 3.00x$, $R^2 = 34.7\%$ which has been added to aid with graphical visualisation.

Secondary Analysis

Group 2 was found to have higher mathematics anxiety than Group 1 at the post-test (Wilcoxon-test: $W = 713$, $p < 0.01$, $95\%CI = [0.462,\ 1.385]$, $d = 1.098$).

There was not a significant correlation found between performance accuracy and mathematics anxiety levels at the post-test (Spearman rank correlation coefficient: $S = 40\,069$, $p = 1.00$, $\rho = -0.059$). There was a significant negative correlation between confidence ratings and mathematics anxiety levels at the post-test (Spearman rank correlation coefficient: $S = 52\,739$, $p = 0.0381$, $\rho = -0.396$).

Hypothesis 4: Personality traits

Primary Analysis

There were no significant correlations found between the hypothesised personality traits and performance accuracy at the pre-test.

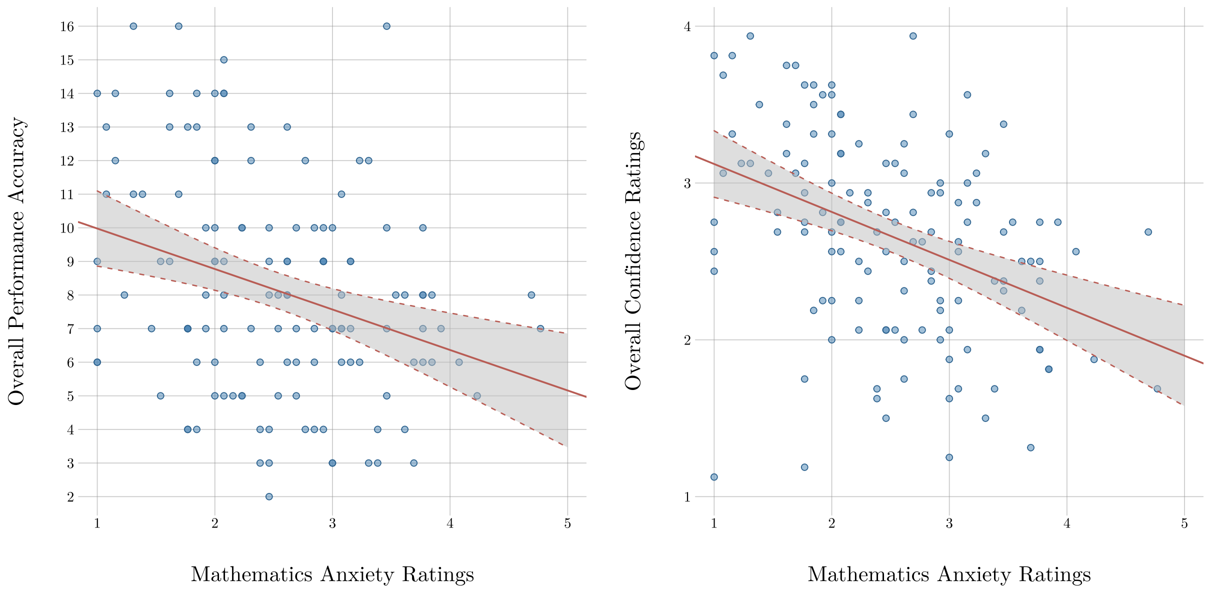
Figure 6.6 | Boxplots showing the mathematics anxiety ratings for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in mathematics anxiety ratings between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

There was a significant positive correlation between levels of neuroticism and mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 211\,483$, $p < 0.001$, $\rho = 0.448$).

Secondary Analysis

There were no significant correlations found between the hypothesised personality traits and performance accuracy at the post-test.

There was a significant positive correlation between levels of neuroticism and mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 17\,640$, $p < 0.001$, $\rho = 0.534$).



(a) $\hat{y} = 11.18 - 1.20x$, $R^2 = 9.5\%$
Overall performance accuracy (y) and mathematics anxiety score (x)

(b) $\hat{y} = 3.43 - 0.31x$, $R^2 = 15.8\%$
Overall confidence judgments (y) and mathematics anxiety score (x)

Figure 6.7 | Scatterplots illustrating the statistically significant Spearman rank correlations for mathematics anxiety at the pre-test. We have added simple linear regression models to aid with graphical visualisation.

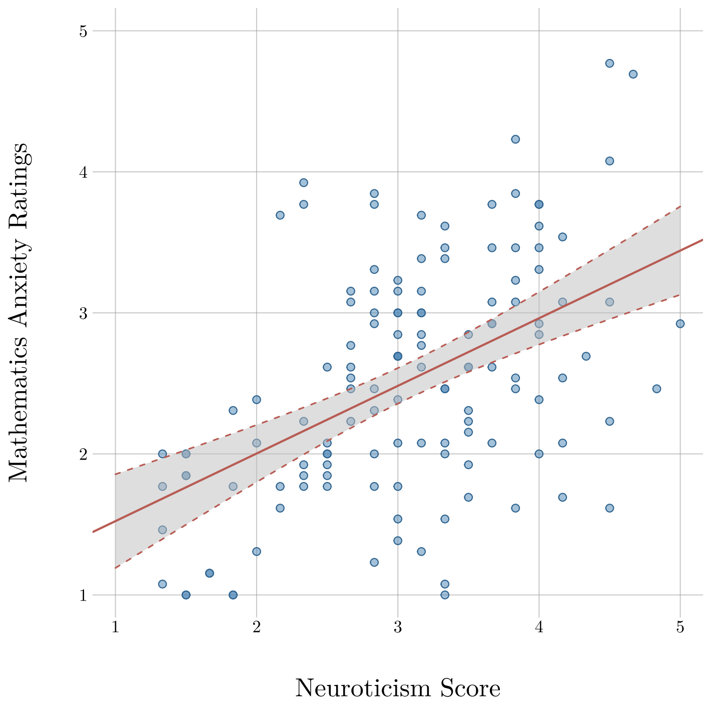


Figure 6.8 | Scatterplot showing the statistically significant correlation between the mathematics anxiety ratings and neuroticism scores at the pre-test. This plot also shows a simple linear regression model $\hat{y} = 1.04 + 0.48x$, $R^2 = 23.9\%$ which has been added to aid with graphical visualisation.

6.3.2 Exploratory Analysis of the Results of the Lab-based Study

Path analysis models

The path analysis model for the pre-test is given by Figure 6.9. The model explained 57.4% of the variance within the numeracy performance score, 34.2% of the variance within the statistics performance score and 26.2% of the variance within the mathematics anxiety score. In this model, the positive path coefficient for *Post-16 Mathematics* on *Mathematics Anxiety Score* indicates that presence of a post-16 mathematics qualification had a negative effect on mathematics anxiety scores.

The path analysis model for the post-test is given in Figure 6.10. The model explained 22.1% of the variance within the numeracy performance score, 37.0% of the variance within the statistics performance accuracy score, 43.1% of the variance within the mathematics anxiety score and 55.4% of the variance within the numeracy confidence judgments. In this model, the sign of the path coefficients for *Post-16 Mathematics* indicates the direction of the effect for presence of a post-16 mathematics qualification.

The goodness-of-fit indices for the models in Figure 6.9 and Figure 6.10 are summarised in Table 6.12.

Table 6.12 | Goodness-of-fit indices for the path analysis models.

	RMSEA [90%CI]	χ^2	SRMR	TLI	CFI
Pre-test	0.000 [0.000, 0.101]	$\chi^2 = 4.914,\ df = 6,\ p = 0.555$	0.030	1.015	1.000
Post-test	0.127, [0.047, 0.201]	$\chi^2 = 23.774,\ df = 12,\ p = 0.022$	0.073	0.834	0.909

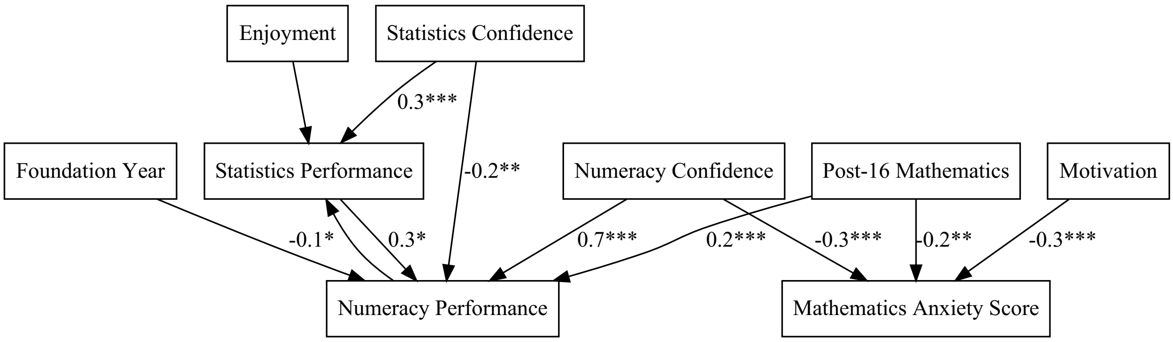


Figure 6.9 | Path analysis model for the pre-test. The path coefficients are standardised and their level of significance are indicated by ∗ (< 0.05), ∗∗ (< 0.01), and ∗ ∗ ∗ (< 0.001).

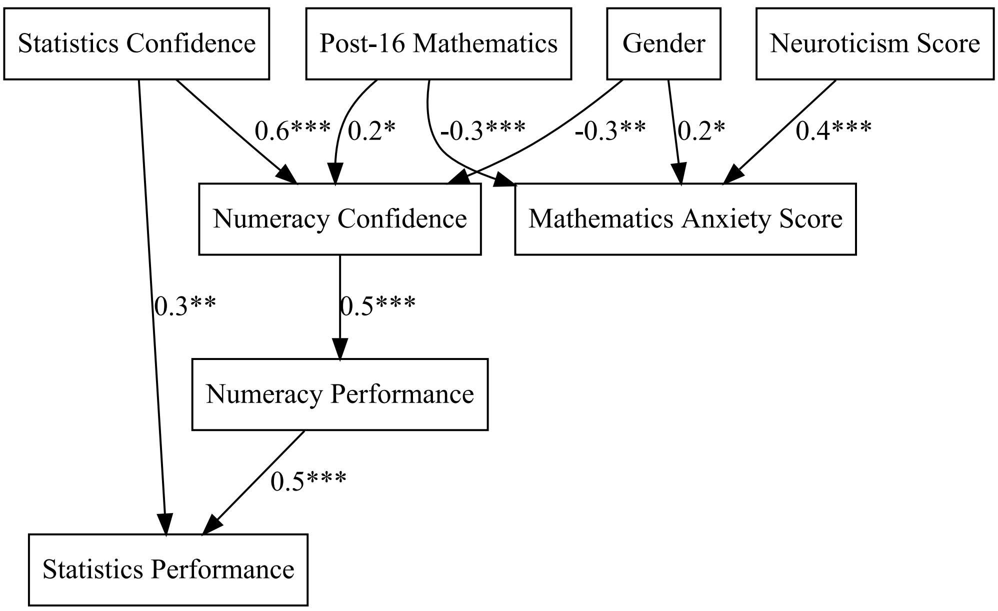


Figure 6.10 | Path analysis model for the pre-test. The path coefficients are standardised and their level of significance are indicated by ∗ (< 0.05), ∗∗ (< 0.01), and ∗ ∗ ∗ (< 0.001).

Attitudes towards mathematics

We also performed preliminary analysis to detect if there were differences between Group 1 and Group 2 for the scores on the ATMI. These findings are presented in Table 6.13.

Table 6.13 | Means, standard deviations, t-scores, p-values and effect sizes for the ATMI subscales by groups.

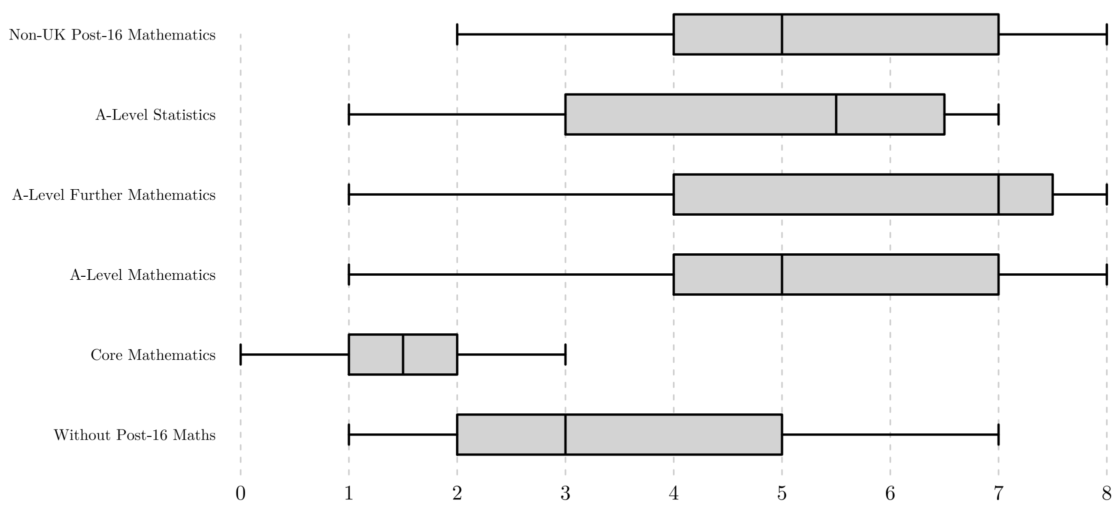
	Attitude Subscale	With Post-16 Mathematics		Without Post-16 Mathematics		t-value	95%CI		p-value	Effect Size
		n	Mean (SD)	n	Mean (SD)		Lower	Higher		
Pre-test	Enjoyment	72	16.4 (5.92)	60	14.2 (5.38)	-2.25	-4.2	-0.27	0.0261	-0.39
	Motivation	72	12.2 (4.75)	60	10.0 (4.27)	-2.73	-3.73	-0.59	<0.01	-0.48
	Sense of Security	72	16.6 (5.50)	60	13.7 (5.05)	-3.1	-4.7	-1.04	<0.01	-0.54
	Value	72	19.7 (4.58)	60	19.2 (4.14)	-0.71	-2.06	0.98	0.4812	-0.12
Post-test	Enjoyment	35	17.9 (5.68)	26	14.5 (5.74)	-2.3	-6.35	-0.44	0.025	-0.6
	Motivation	35	13.7 (4.39)	26	9.8 (4.40)	-3.38	-6.13	-1.57	<0.01	-0.88
	Sense of Security	35	17.0 (5.10)	26	12.0 (5.38)	-3.67	-7.67	-2.26	<0.001	-0.95
	Value	35	20.8 (3.84)	26	18.8 (3.49)	-2.05	-3.88	-0.05	0.0446	-0.53

Differences between post-16 mathematics qualifications

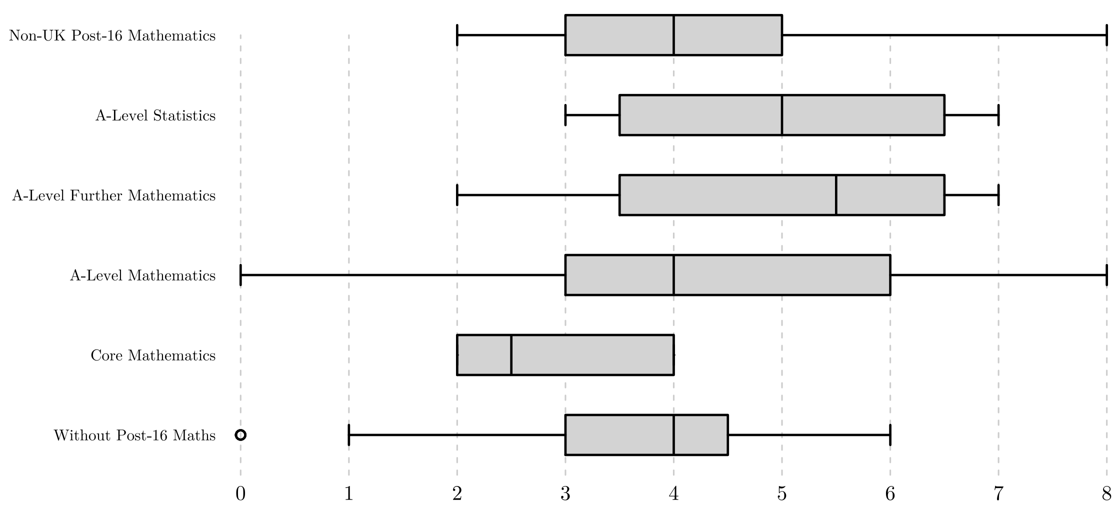
In order to verify whether differences between the groups with and without a post-16 mathematics qualification found in Section 6.3.1 were driven by particular post-16 qualifications, we performed visual analysis using boxplots. Since there were insufficient numbers of participants taking individual qualifications to perform additional sub-group analysis, we opted to restrict the visual analysis to the pre-test where there were a higher number of participants.

Figure 6.11 shows the differences in performance accuracy on each of the numeracy and statistics items. We can observe that performance accuracy on the numeracy questions is generally higher for most qualifications than not having a post-16 mathematics qualification. Performance accuracy levels were slightly more similar on the statistics questions, however some post-16 mathematics qualifications such as A-Level Statistics and A-Level Further Mathematics were the highest. Core Mathematics had the lowest performance on both the numeracy and statistics questions, even when compared to participants without a post-16 mathematics qualification.

Figure 6.12 shows the confidence judgments on each of the numeracy and statistics items. This suggested that the differenes between the qualifications were less consistent. For example,



(a) Performance accuracy on the numeracy questions.

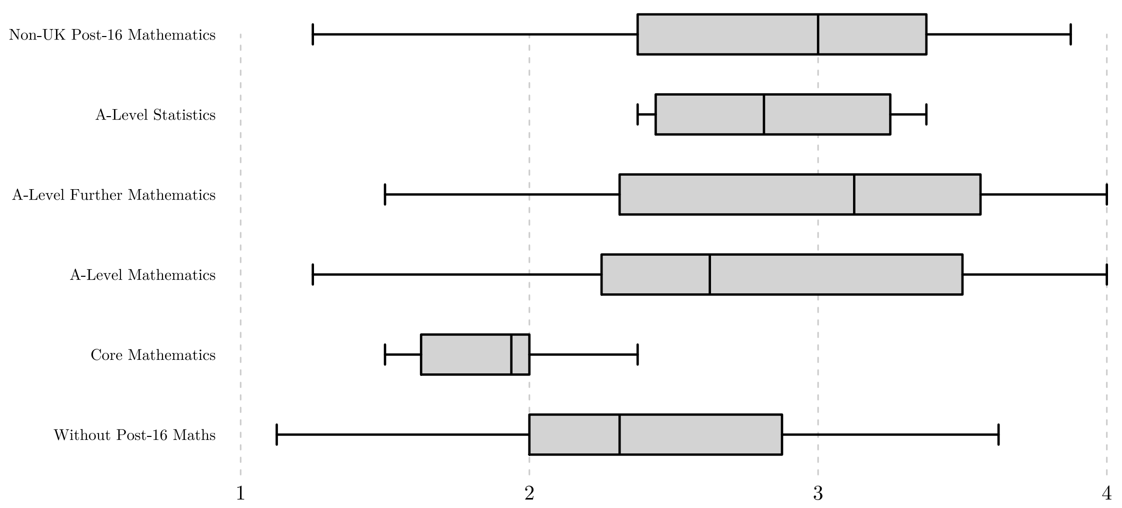


(b) Performance accuracy on the statistics questions.

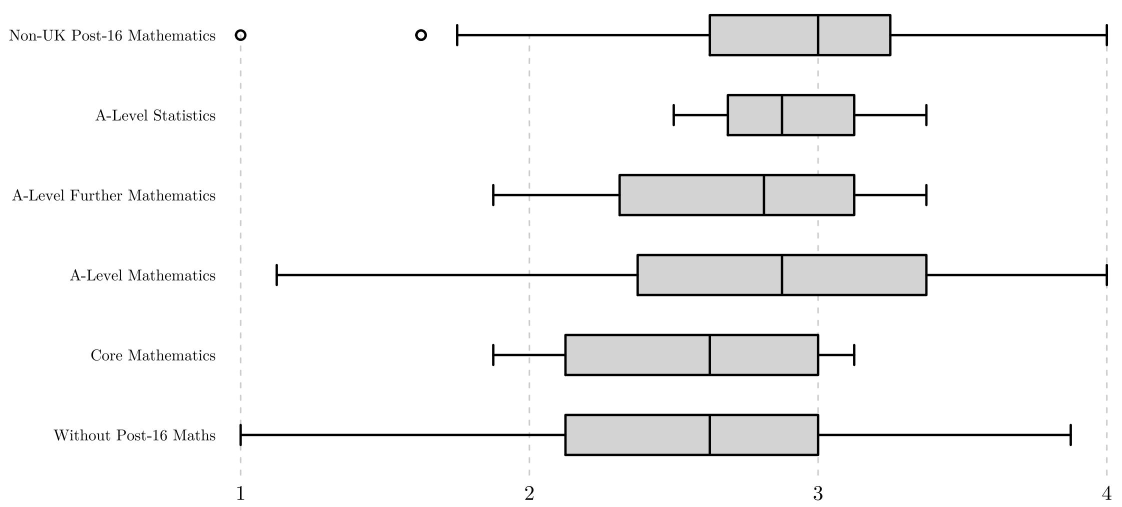
Figure 6.11 | Boxplots of the performance accuracy at the pre-test for individual post-16 mathematics qualifications.

participants with A-Level Further Mathematics appeared to have highest levels of confidence on the numeracy questions, however this was less prominent on the statistics questions. In addition, participants with Core Mathematics appeared to be less confident on the numeracy questions than participants without a post-16 mathematics qualification, with similar confidence on the statistics questions.

Figure 6.13 shows the differences in mathematics anxiety ratings. We observe that mathematics



(a) Confidence judgments on the numeracy questions.



(b) Confidence judgments on the statistics questions.

Figure 6.12 | Boxplots of the confidence judgments at the pre-test for individual post-16 mathematics qualifications.

anxiety ratings were generally lower for all post-16 mathematics qualifications, with participants without a post-16 mathematics qualification suggested to have the highest average as well as the widest variation in ratings.

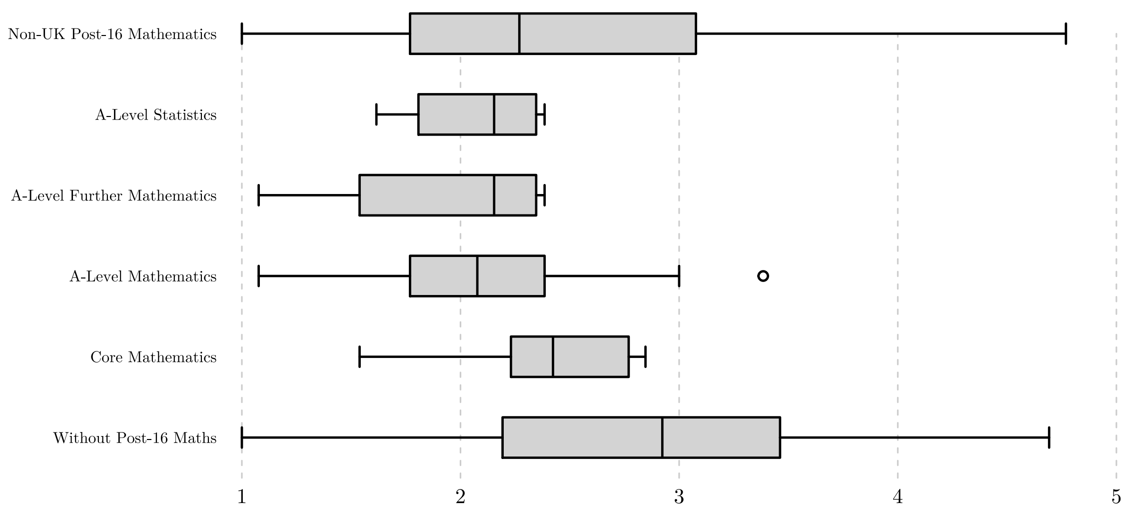


Figure 6.13 | Boxplots of the mathematics anxiety ratings at the pre-test for individual post-16 mathematics qualifications.

6.4 Results of the Online Study

For brevity and clarity we will refer to Group 1 and Group 2 as:

Group 1: Participants who had studied a post-16 mathematics qualification.

Group 2: Participants who had not studied a post-16 mathematics qualification.

6.4.1 Pre-registered Main Analysis of the Online Study

Hypothesis 1: Performance accuracy in numeracy and statistics tests

Primary Analysis

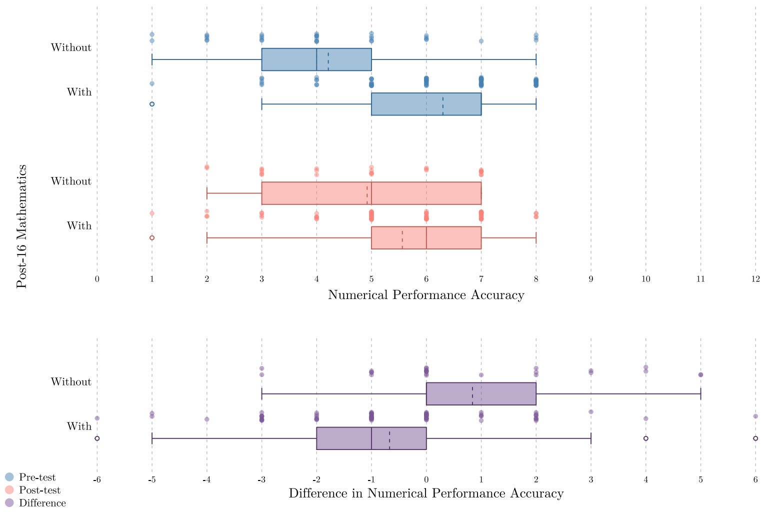
Group 1 was found to exhibit higher performance accuracy on the numeracy and statistics test at the pre-test (Wilcoxon-test: $W = 504.5$, $p < 0.001$, $95\%CI = [-6.000, -3.000]$, $d = -1.310$), however there was no significant difference between the group at the post-test (Wilcoxon-test: $W = 721$, $p = 0.1159$, $95\%CI = [-2.000, 0.000]$, $d = -0.342$).

There was a significant difference in the change in performance accuracy between the pre-test and the post-test with Group 2 exhibiting a greater overall change in performance than Group 1 (Wilcoxon-test: $W = 1331$, $p < 0.01$, $95\%CI = [0.500, 2.000]$, $d = 0.769$).

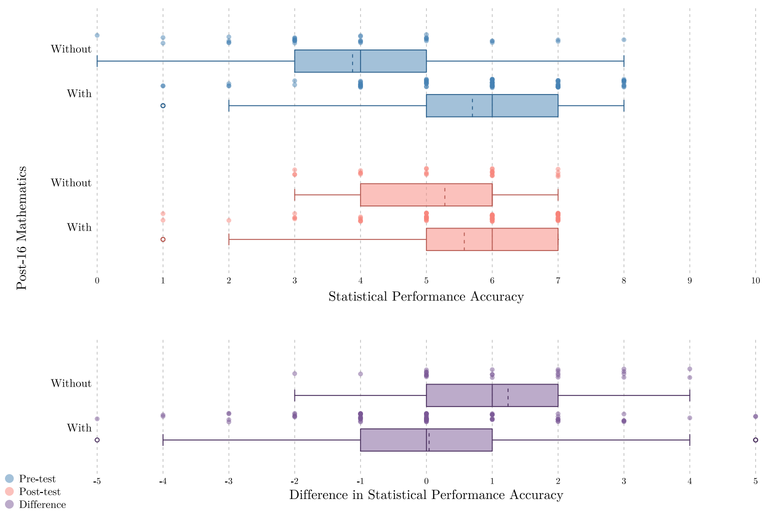
Secondary Analysis

Group 1 were found to have better performance accuracy on the numeracy items at the pre-test compared to Group 2 (Wilcoxon-test: $W = 561$, $p < 0.001$, $95\%CI = [-3.000, -2.000]$, $d = -1.249$), but this was not the case at the post-test (Wilcoxon-test: $W = 720.5$, $p = 1.00$, $95\%CI = [-2.000, 0.000]$, $d = -0.399$).

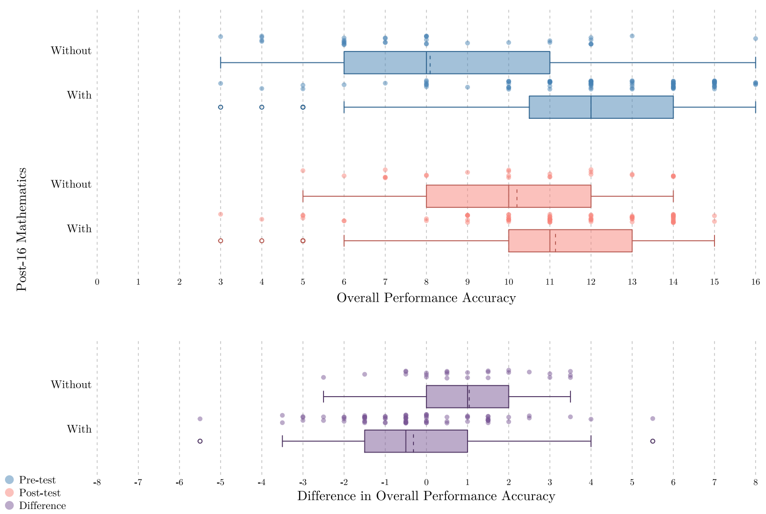
Group 1 were also found to have better performance accuracy on the statistics items at the pre-test compared to Group 2 (Wilcoxon-test: $W = 626.5$, $p < 0.001$, $95\%CI = [-3.000, -1.000]$, $d = -1.052$), but this was not the case at the post-test (Wilcoxon-test: $W = 761$, $p = 1.00$, $95\%CI = [-1.000, 0.000]$, $d = -0.211$).



(a) Performance accuracy scores on the numeracy tests.



(b) Performance accuracy scores on the statistics tests.



(c) Overall performance accuracy scores.

Figure 6.14 | Boxplots showing the overall performance accuracy scores for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in performance accuracy scores between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

There was also no significant difference in the change in performance accuracy for the groups between the pre-test and the post-test on the numeracy items (Wilcoxon-test: $W = 1262$, $p = 0.0945$, $95\%CI = [0.000, 2.000]$, $d = 0.721$) or on the statistics items (Wilcoxon-test: $W = 1261$, $p = 0.0947$, $95\%CI = [0.000, 2.000]$, $d = 0.643$).

Hypothesis 2: Retrospective confidence judgments

Primary Analysis

Group 1 were found to exhibit higher confidence ratings when answering the numeracy and statistics questions at the pre-test than Group 2 (Wilcoxon-test: $W = 800$, $p < 0.01$, $95\%CI = [-0.625, -0.187]$, $d = -0.754$).

There was a significant positive correlation between confidence ratings and performance accuracy at the pre-test (Spearman rank correlation coefficient: $S = 94\,783$, $p < 0.001$, $\rho = 0.636$).

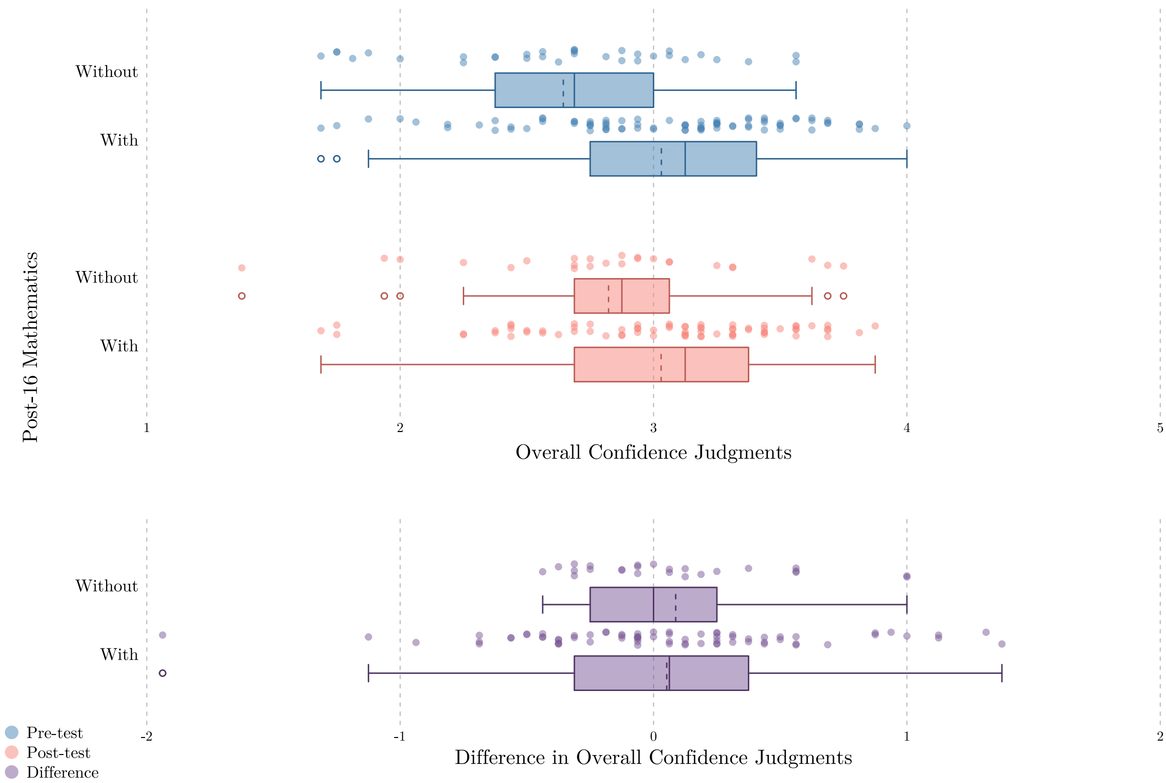


Figure 6.15 | Boxplots showing the overall confidence judgments for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in confidence judgments between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.

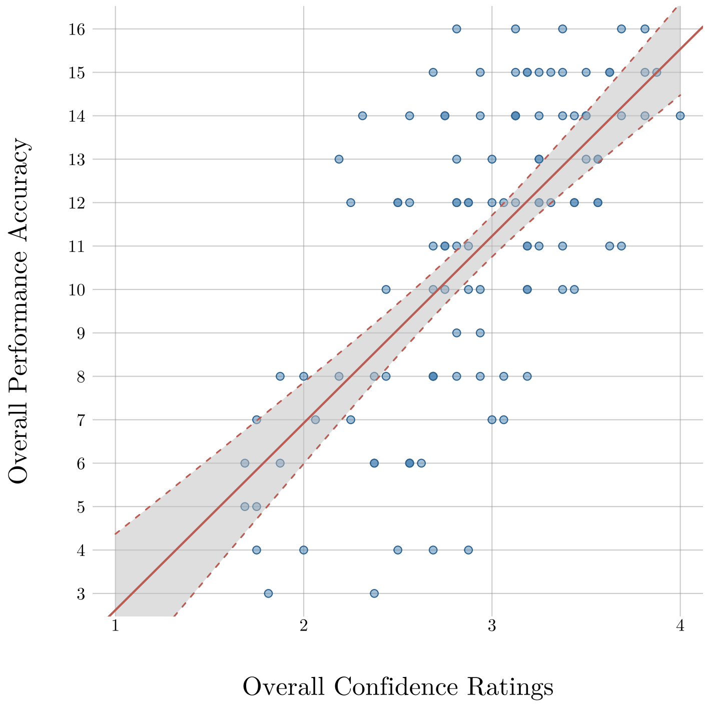


Figure 6.16 | Scatterplot showing the statistically significant correlation between the overall performance accuracy and the overall confidence judgments at the pre-test. This plot also shows a simple linear regression model $\hat{y} = -1.69 + 4.31x$, $R^2 = 45.3\%$ which has been added to aid with graphical visualisation.

Secondary Analysis

There was no significant difference in the confidence ratings between Group 1 and Group 2 at the post-test (Wilcoxon-test: $W = 694$, $p = 1.00$, $95\%CI = [-0.438, 0.000]$, $d = -0.410$). Group 1 exhibited higher confidence ratings than Group 2 on the numeracy questions at the pre-test (Wilcoxon-test: $W = 627.5$, $p < 0.001$, $95\%CI = [-0.875, -0.375]$, $d = -1.083$), however there was no significant difference between the groups for the confidence ratings on the statistics questions at the pre-test (Wilcoxon-test: $W = 1133.5$, $p = 1.00$, $95\%CI = [-0.375, 0.000]$, $d = -0.271$). There were also no significant differences between the groups for the confidence ratings on the numeracy questions at the post-test (Wilcoxon-test: $W = 620$, $p = 0.4243$, $95\%CI = [-0.625, 0.000]$, $d = -0.573$) or the statistics questions at the post-test (Wilcoxon-test: $W = 818.5$, $p = 1.00$, $95\%CI = [-0.375, 0.125]$, $d = -0.168$).

There was a significant positive correlation between confidence ratings and performance accuracy at the post-test (Spearman rank correlation coefficient: $S = 67\,824$, $p < 0.001$, $\rho = 0.568$).

Hypothesis 3: Mathematics anxiety

Primary Analysis

There was no significant difference between the mathematics anxiety levels of either group at the pre-test (Wilcoxon-test: $W = 1750.5$, $p = 0.2573$, $95\%CI = [0.077, 0.692]$, $d = 0.533$).

There was a significant negative correlation between performance accuracy and mathematics anxiety levels at the pre-test (Spearman rank correlation coefficient: $S = 343\,143$, $p < 0.01$, $\rho = -0.319$). There was also a significant negative correlation between confidence ratings and mathematics anxiety levels at the pre-test (Spearman rank correlation coefficient: $S = 366\,798$, $p < 0.001$, $\rho = -0.410$).

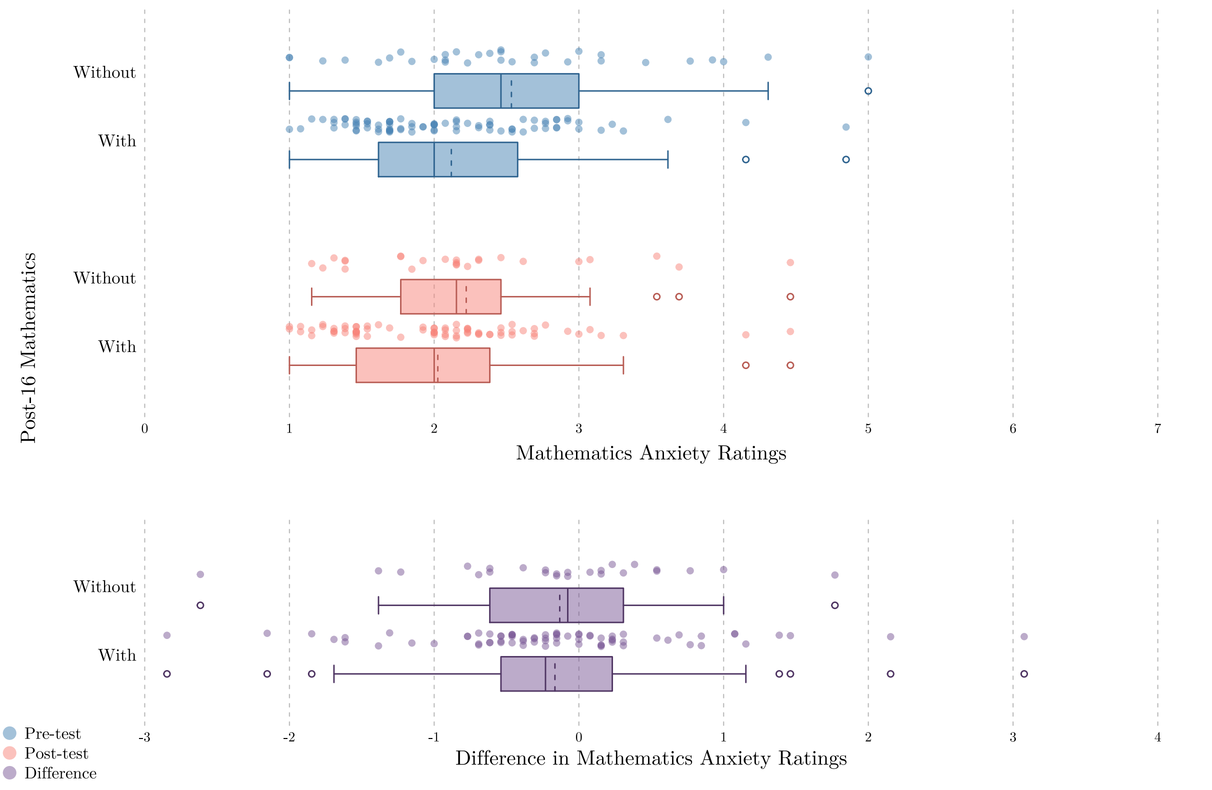
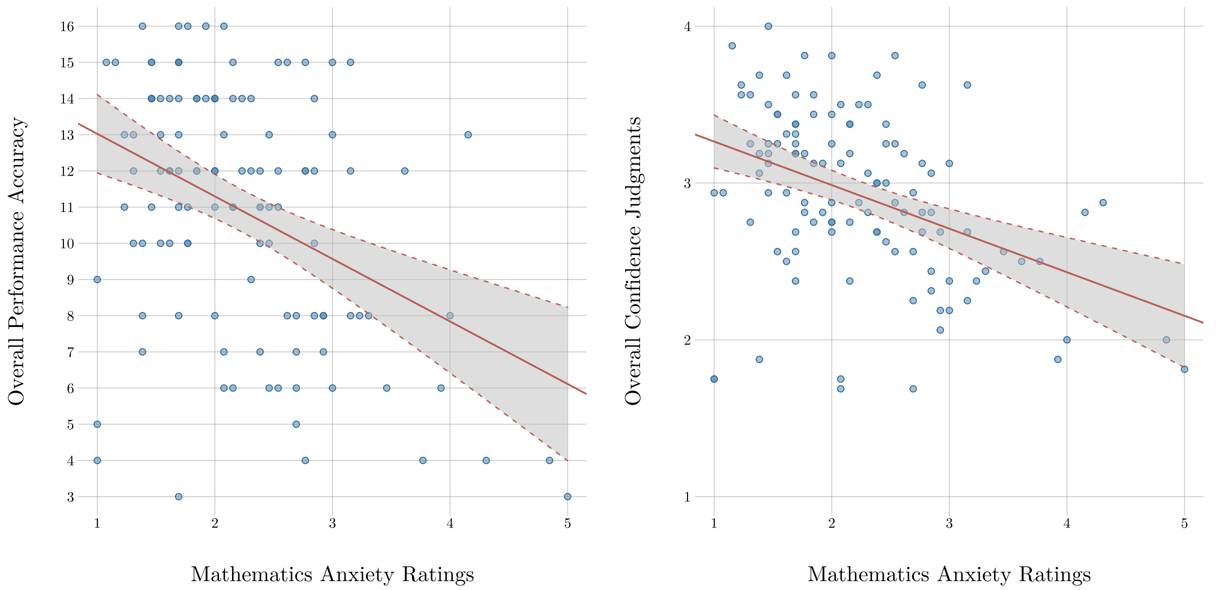


Figure 6.17 | Boxplots showing the mathematics anxiety ratings for Group 1 and Group 2 at the pre-test and the post-test. Also shown are the differences in mathematics anxiety ratings between the pre-test and the post-test. The median and mean lines for each group are displayed as a solid and dashed line, respectively.



(a) $\hat{y} = 14.75 - 1.73x$, $R^2 = 15.9\%$
Overall performance accuracy (y) and mathematics anxiety score (x)

(b) $\hat{y} = 3.54 - 0.28x$, $R^2 = 16.8\%$
Overall confidence judgments (y) and mathematics anxiety score (x)

Figure 6.18 | Scatterplots illustrating the statistically significant Spearman rank correlations for mathematics anxiety at the pre-test. We have added simple linear regression models to aid with graphical visualisation.

Secondary Analysis

There was no significant difference between the mathematics anxiety levels of either group at the post-test (Wilcoxon-test: $W = 1008.5$, $p = 1.00$, $95\%CI = [-0.154, 0.462]$, $d = 0.271$).

There was no significant correlation between performance accuracy and mathematics anxiety levels at the post-test (Spearman rank correlation coefficient: $S = 188\,284$, $p = 1.00$, $\rho = -0.200$). There was, however, a significant negative correlation between confidence ratings and mathematics anxiety levels at the post-test (Spearman rank correlation coefficient: $S = 219\,239$, $p < 0.01$, $\rho = -0.398$).

Hypothesis 4: Personality traits

Primary Analysis

There were no significant correlations found between the hypothesised personality traits an performance accuracy at the pre-test.

There was a significant positive correlation between levels of neuroticism and mathematics anxiety at the pre-test (Spearman rank correlation coefficient: $S = 166\,513$, $p < 0.001$, $\rho = 0.360$).

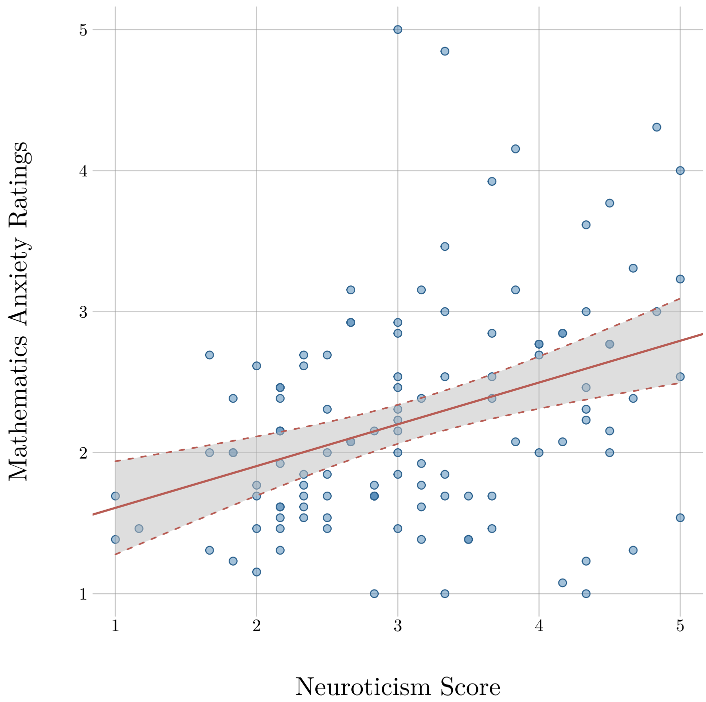


Figure 6.19 | Scatterplot showing the statistically significant correlation between the mathematics anxiety ratings and neuroticism scores at the pre-test. This plot also shows a simple linear regression model $\hat{y} = 1.31 + 0.30x$, $R^2 = 13.1\%$ which has been added to aid with graphical visualisation.

Secondary Analysis

There were no significant correlations found between the hypothesised personality traits an performance accuracy at the post-test.

There was not a significant correlation between levels of neuroticism and mathematics anxiety at the post-test (Spearman rank correlation coefficient: $S = 149\,484$, $p = 1.00$, $\rho = 0.047$).

6.4.2 Exploratory Analysis of the Results of the Online Study

Path analysis models

The path analysis model for the pre-test is given by Figure 6.20. The model explained 57.1% of the variance within the numeracy performance score, 52.2% of the variance within the statistics performance score and 29.3% of the variance within the mathematics anxiety score. In this model, the sign of the path coefficients for *Post-16 Mathematics* indicate the direction of the effect for presence of a post-16 mathematics qualification.

The path analysis model for the post-test is given in Figure 6.21. The model explained 38.5% of the variance within the numeracy performance score, 53.0% of the variance within the statistics performance accuracy score and 49.4% of the variance within the numeracy confidence judgments. In this model, the positive path coefficient for *Post-16 Mathematics* on *Numeracy Confidence* indicates that presence of a post-16 mathematics qualification had a positive effect of numeracy confidence judgments.

The goodness-of-fit indices for the models in Figure 6.20 and Figure 6.10 are summarised in Table 6.14.

Table 6.14 | Goodness-of-fit indices for the path analysis models.

	RMSEA [90%CI]	χ^2	**SRMR**	**TLI**	**CFI**
Pre-test	0.000 [0.000, 0.088]	$\chi^2 = 9.632,\ df = 11,\ p = 0.564$	0.030	1.012	1.000
Post-test	0.036 [0.000, 0.122]	$\chi^2 = 10.116,\ df = 9,\ p = 0.341$	0.042	0.988	0.994

Attitudes towards mathematics

We also performed preliminary analysis to detect if there were differences between Group 1 and Group 2 for the scores on the ATMI. These findings are presented in Table 6.15. We found that Group 1 had significantly higher attitude scores in all four subscales at the pre-test than Group 2. At the post-test, Group 1 were significantly higher in the enjoyment and motivation subscales only.

Differences between post-16 mathematics qualifications

In order to verify whether differences between the groups with and without a post-16 mathematics qualification found in Section 6.4.1 were driven by particular post-16 qualifications, we performed visual analysis using boxplots. Since there were insufficient numbers of participants taking individual qualifications to perform additional sub-group analysis, we opted to restrict

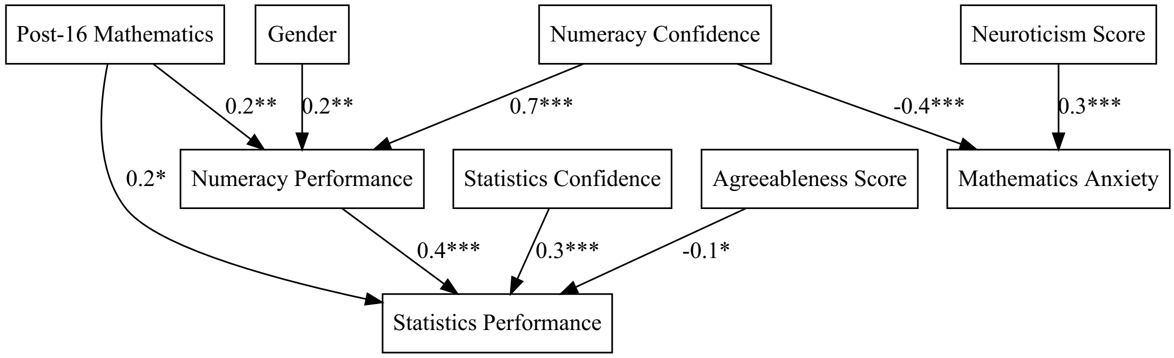


Figure 6.20 | Path analysis model for the pre-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $***$ (< 0.001).

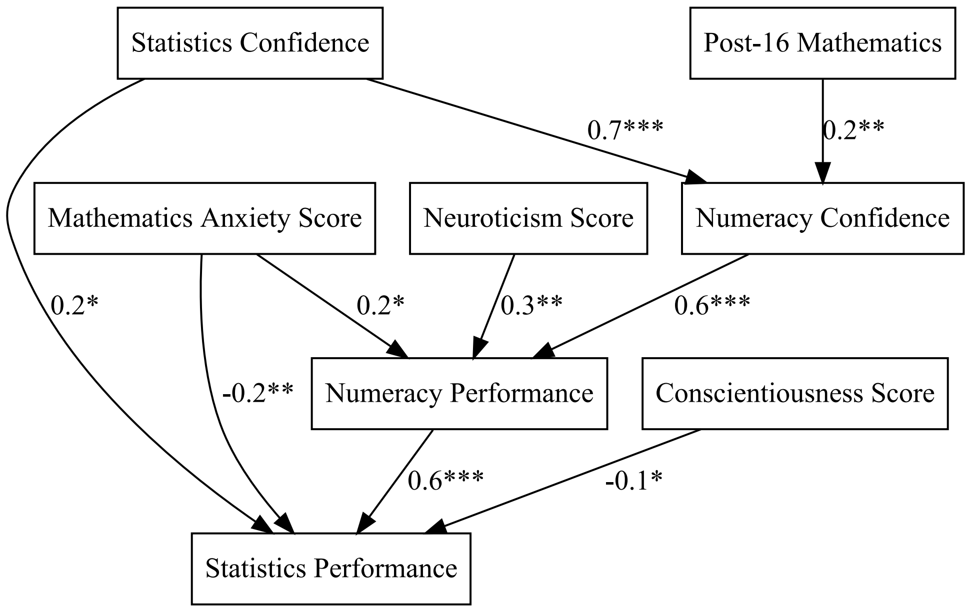


Figure 6.21 | Path analysis model for the post-test. The path coefficients are standardised and their level of significance are indicated by $*$ (< 0.05), $**$ (< 0.01), and $***$ (< 0.001).

Table 6.15 | Means, standard deviations, *t*-scores, *p*-values and effect sizes for the ATMI subscales by groups.

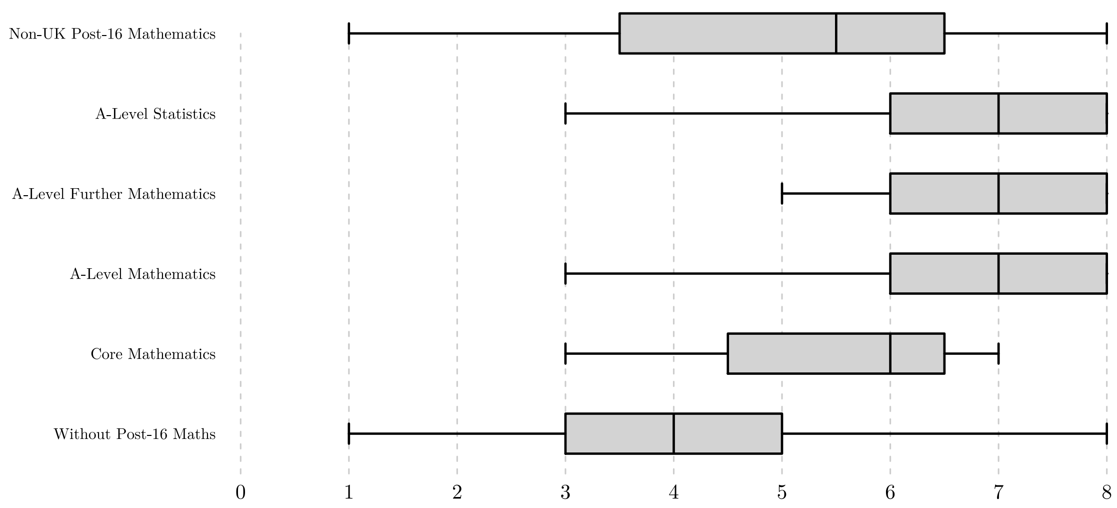
	Attitude Subscale	With Post-16 Mathematics		Without Post-16 Mathematics		*t*-value	95%CI		*p*-value	Effect Size
		n	Mean (SD)	n	Mean (SD)		Lower	Higher		
Pre-test	Enjoyment	83	20.3 (4.07)	33	13.0 (4.85)	-8.28	-9.09	-5.58	<0.001	-1.70
	Motivation	83	14.6 (3.92)	33	9.3 (4.15)	-6.49	-6.95	-3.70	<0.001	-1.34
	Sense of Security	83	18.4 (4.46)	33	14.6 (5.47)	-3.92	-5.79	-1.90	<0.001	-0.81
	Value	83	21.3 (2.99)	33	19.5 (4.17)	-2.68	-3.23	-0.49	<0.01	-0.55
Post-test	Enjoyment	73	19.6(4.51)	25	16.2 (5.98)	-2.95	-5.63	-1.10	<0.01	-0.68
	Motivation	73	14.7 (3.99)	25	11.6 (5.28)	-3.14	-5.17	-1.17	<0.01	-0.73
	Sense of Security	73	18.2 (4.37)	25	16.9 (5.31)	-1.16	-3.37	0.88	0.2481	-0.27
	Value	73	20.7 (3.42)	25	19.8 (4.81)	-1.08	-2.71	0.80	0.2838	-0.25

the visual analysis to the pre-test where there were a higher number of participants.

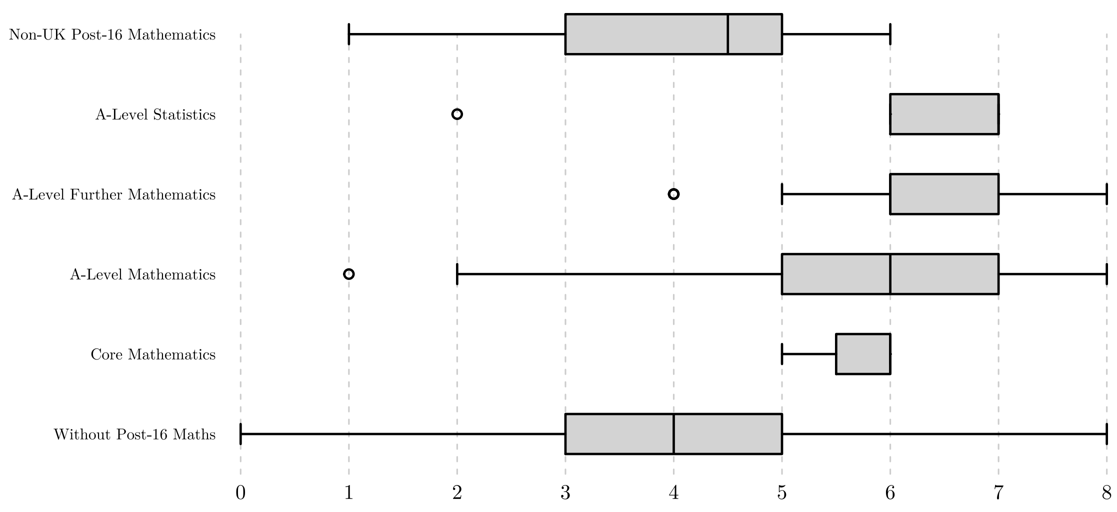
Figure 6.22 shows the differences in performance accuracy on each of the numeracy and statistics items. We can observe that the statistical differences found in Section 6.4.1 were supported by these boxplots. Indeed, participants with any of the individual post-16 mathematics qualifications exhibited consistently higher performance accuracy than participants without a post-16 mathematics qualification.

Figure 6.23 shows the confidence judgments on each of the numeracy and statistics items. We can observe that participants without a post-16 mathematics qualification were less confident on the numeracy questions than their counterparts. We can also observe that there is no clear difference between the individual post-16 mathematics qualifications and the confidence judgments on the statistics questions. This supports the findings in Section 6.4.1.

Figure 6.24 shows the differences in mathematics anxiety ratings. We can see that the mathematics anxiety ratings were mixed between the groups with no clear difference between the groups. This supports the results found in Section 6.4.1.

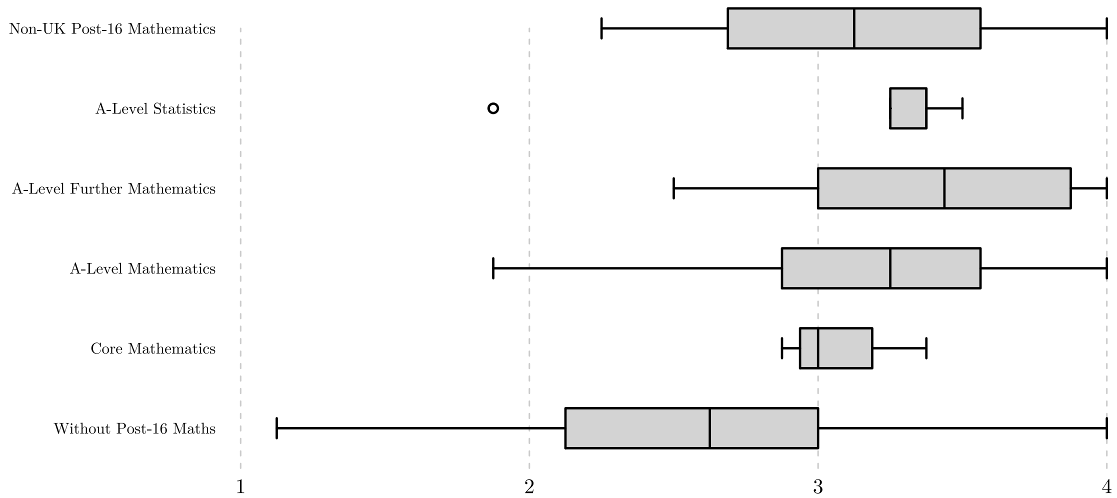


(a) Performance accuracy on the numeracy questions.

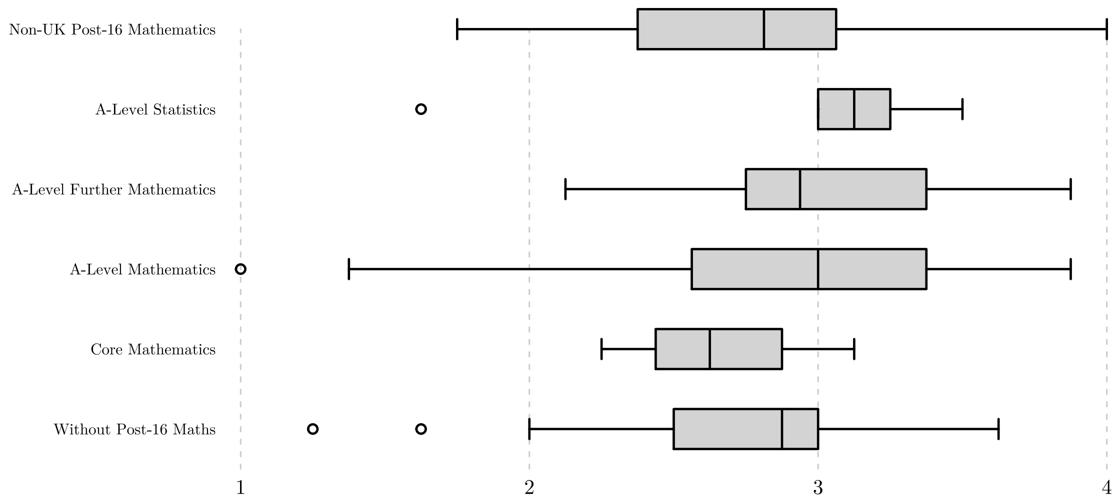


(b) Performance accuracy on the statistics questions.

Figure 6.22 | Boxplots of the performance accuracy at the pre-test for individual post-16 mathematics qualifications.



(a) Confidence judgments on the numeracy questions.



(b) Confidence judgments on the statistics questions.

Figure 6.23 | Boxplots of the confidence judgments at the pre-test for individual post-16 mathematics qualifications.

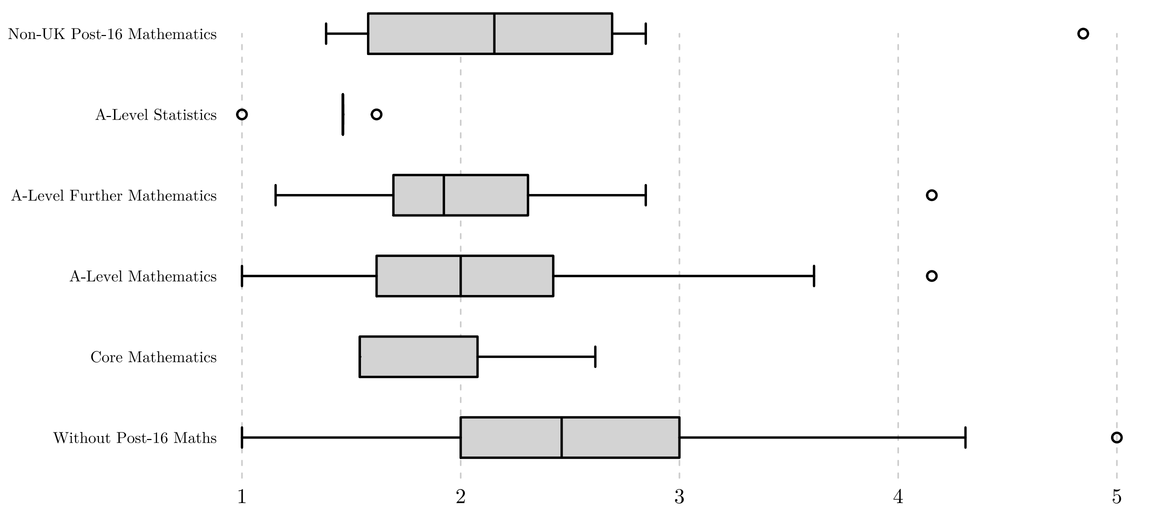


Figure 6.24 | Boxplots of the mathematics anxiety ratings at the pre-test for individual post-16 mathematics qualifications.

6.5 Discussion

This study aimed to establish the predictors of mathematics performance for students who had just started their university degree course by using participants from the University of Essex as well as other university institutions.

6.5.1 Discussion of the Lab-based Study

We found that participants who had studied a post-16 mathematics qualification performed statistically better on the numeracy and statistics tests than participants who had not at the pre-test, however this difference was not true at the post-test. Indeed, when we explore the differences on the individual numeracy and statistics components of the test, we see that those with a post-16 mathematics qualification only perform better on the numeracy at the pre-test, however no significant difference was observed between the groups on the statistics tests. This suggests that statistics knowledge is weaker, irrespective of whether a participant has studied a post-16 mathematics qualification. Whilst there was a significant positive correlation between confidence judgments and performance accuracy, there was no difference in the confidence levels of either group, even when analysing the confidence judgments on the numeracy and statistics components of the test. This suggests that although participants were generally able to establish whether they got the question correct, having a post-16 mathematics qualification made them no better at doing this.

We also found that participants without a post-16 mathematics qualification had significantly higher levels of mathematics anxiety both at the pre-test and after one term of intervention from University teaching. This, in turn had negative associations with confidence levels at both the pre-test and post-test, and performance accuracy at the pre-test. This indicates that presence of a post-16 mathematics qualification means that students are less likely to be mathematically anxious as well as more confident which in turn is beneficial for performance on mathematics-based tasks.

Whilst we did not observe any correlations between performance and particular personality traits, we did find a significant positive correlation between levels of neuroticism and mathematics anxiety at the pre- and post-test.

The path analysis models revealed interesting causal relationships between variables. Firstly, we found that although mathematics anxiety ratings did not predict any variables, it was predicted by whether a participant had a post-16 mathematics qualification with those who had a post-16 mathematics qualification tending to experience lower levels of mathematics anxiety. In addition, it was predicted by numeracy confidence at the pre-test and neuroticism at the post-test. Gender was also a significant predictor at the post-test, with females tending to be more mathematically anxious than males. This difference also led to a greater change in mathematics anxiety ratings between the pre-test and the post-test for the females. We also found that numeracy confidence predicted numeracy performance, however statistics confidence predicted both numeracy and statistics confidence at the pre-test, suggesting that participants who were more likely to rate themselves as confident on statistics questions were also more likely to perform better on numeracy questions. This may be because statistics relies on numeracy knowledge and skill, however numeracy does not rely on statistics knowledge.

As well as being a predictor of mathematics anxiety, the path analysis models also showed that post-16 mathematics was a significant predictor of performance accuracy on the numeracy questions. In addition, participants who had studied a foundation year were also positively associated with numeracy performance at the pre-test. This suggests that previous mathematics experience (whether through post-16 mathematics qualifications or studying a foundation year) has a positive effect on numeracy performance, although not for statistics performance. In addition to this, we found that participants who had not studied a post-16 maths qualification were more likely to improve in scores, however this difference in scores between groups was not found to be significant using the pre-registered analysis.

The path analysis models also showed that there was an interplay between numeracy and statistics performance at the pre-test i.e., participants who performed well on numeracy questions also performed well on statistics questions and the reverse implication was true. However, this was a one-directional relationship at the post-test with high performance on the numeracy questions associated with high performance on the statistics questions.

The path analysis models also revealed some significant relationships for the changes in performance accuracy. In particular, we found that females were more likely to show an improvement in performance accuracy scores between the pre- and post-test. In addition, we also showed that participants who possessed high levels of the agreeableness personality trait were less likely to show an improvement in the performance accuracy scores between the pre- and post-test.

When considering attitudes towards mathematics, we saw that both groups of participants valued mathematics highly, however participants who had studied a post-16 mathematics qualification were more motivated to learn the subject as well as feeling secure when engaging with mathematics-based tasks.

6.5.2 Discussion of the Online Study

We found that participants with a post-16 mathematics qualification tended to perform better on the numeracy and statistics questions at the pre-test. However, there were no differences at the post-test which implies that the participants without post-16 mathematics had closed the performance gap. Indeed, when analysing these differences we found that participants without a post-16 mathematics qualification exhibited a larger improvement in performance accuracy than their counterparts. This implies that one term of university teaching was sufficient for participants without post-16 mathematics to close the performance gap and exhibit sufficiently similar performance levels as their counterparts.

We also found that participants with a post-16 mathematics qualification exhibited higher levels of confidence when answering both numeracy and statistics questions. Indeed, we also found that confidence judgments were positively correlated with performance accuracy. Interestingly, we found no significant differences between the confidence judgments of each group. This was despite the fact that there were differences in performance accuracy and the fact that positive correlations between confidence judgments and performance accuracy remained. This may be because participants without a post-16 mathematics qualification had closed the performance gap by the post-test and so both groups were also more confident at completing such questions.

When analysing differences in attitudes towards mathematics for each group, we found that participants who had studied a post-16 mathematics qualification had significantly higher attitudes at the pre-test in all subscales. However, by the post-test these differences were only significant in the subscales enjoyment and motivation. When exploring the means of these subscales, we see that the value subscale was high-scoring among both groups of individuals which suggests that both groups of participants can see the value in mathematics, regardless of whether they have studied it after the ages of 16. The differences that were observed at the pre- and post-test suggest that participants with a post-16 mathematics qualification remain more motivated to engage with mathematics and that they find it more enjoyable than their counterparts. This may help to give some insight into why students choose to take post-16 mathematics. For instance, our study seems to suggest that even though all participants tended to see the value in studying mathematics, it is only participants who took post-16 mathematics who tend to possess enjoyment and have a higher motivation to learn the subject.

We also performed visual analysis for individual post-16 mathematics qualifications at the pre-test and found that significant differences on performance accuracy and confidence judgments were not driven by participants who had taken a particular type of post-16 mathematics qualification. Reassuringly, we observed that all post-16 mathematics qualifications exhibited better performance at the pre-test on both the numeracy and statistics questions which indicates that having a post-16 mathematics qualification is an advantage when starting at university. This was also true for the confidence judgments on the numeracy test. However, the confidence levels were not clearly different on the statistics test which implies that having a post-16 mathematics qualification did not mean that participants were more confident when answering these types of questions, despite exhibiting higher performance accuracy. Indeed, individuals with a post-16 mathematics qualification had broadly similar levels of confidence as their counterparts without a post-16 mathematics qualification. Perhaps unsurprisingly, the most confident group on the statistics questions were participants who had studied A-Level Statistics, however they were only marginally ahead of other qualifications. Even participants who had studied A-Level Mathematics which contains a prescribed amount of statistics content, including the analysis of a large data set (see Ofqual (2017) for details of the A-Level Mathematics syllabus) appeared to be only marginally more confident on these questions. The visual analysis supported the findings in the pre-registered main analysis that there were no significant differences in the mathematics anxiety ratings.

The path analysis models revealed some interesting causal effects. For example, at the pre-test post-16 mathematics positively predicted performance accuracy on the numeracy questions as did confidence judgments on the numeracy questions. We also found the females were more likely to exhibit higher performance than males on the numeracy questions. Presence of a post-16 mathematics qualification positively predicted statistical performance which is consistent with the correlations found in the pre-registered main analysis. Indeed, statistical confidence was also a positive predictor of statistical performance, however we also found that numeracy performance was a positive predictor of statistical performance. This suggests that better performance on the numeracy questions results in better performance on the statistics questions, however this effect was not observed in the opposite direction which means that a participant needs to have the required skills and knowledge in numeracy in order to succeed in statistics. This is a particularly important finding since we did not find any significant differences between the groups with and without a post-16 mathematics qualification on the statistics questions, but we did on the numeracy questions. Thus, when framing the argument from the perspective of preparedness for quantitative study at university, we see that numeracy performance is of particular importance since this will also feed into statistical ability.

Similar relationships were observed with the path analysis models for the post-test data. For example, we saw that numeracy performance still strongly predicted statistical performance, thus giving further evidence that in order to show high performance in statistics, it is necessary to also have high performance in numeracy. There were a few differences at the post-test, however. For example, lower mathematics anxiety implied better statistical performance, however the reverse association was observed for numeracy performance. This is a surprising result as one would expect a negative association between mathematics anxiety and numeracy performance. Indeed, when exploring correlations between overall performance accuracy and mathematics anxiety we see the expected negative correlations.

When exploring the path analysis models for the differences between the pre- and post-test, we observed that participants without a post-16 mathematics qualification showed the highest level of improvement. Indeed, this finding was supported by the pre-registered analysis and is likely due to participants who had not studied a post-16 mathematics qualification having a bigger performance gap to close. As we discussed in the pre-registered analysis, this gap was closed on each of the the numeracy questions and the statistics questions suggesting that one term of university study is sufficient to close this difference. The path analysis model also suggests that highly neurotic participants were more likely to decrease their level of mathematics anxiety, likely because such individuals were more anxious anyway. These participants who decreased in their levels of mathematics anxiety between the pre-test and the post-test were also likely to increase in their quantitative confidence levels which, in turn, increased their performance. Thus, we can conclude that in order to improve performance on quantitative tasks, one needs to reduce their levels of mathematics anxiety which will improve their confidence levels.

Within the individual personality traits we found that neuroticism was positively correlated with mathematics anxiety. The path analysis models also suggested that conscientiousness was negatively correlated with statistics performance at the post-test, however no other correlations between personality traits and performance accuracy were found. One must be mindful that we used an abbreviated version of the Big Five (the BFI-2-S; Soto & John, 2017b) which was expected to have lower Cronbach's Alpha reliability scores than the full version. Indeed, the online version of our study had a reliability score of $\alpha = 0.616$ for conscientiousness which implies a minimally reliable score, however the reliability score for neuroticism was $\alpha = 0.864$ which suggests a good level of reliability. As such, our results for the relationship between neuroticism and mathematics anxiety appear to be reliable and conform with our hypotheses. In addition, other studies have shown that neuroticism is positively associated with other types of anxiety (O'Connor & Paunonen, 2007; Chamorro-Premuzic et al., 2008), we have evidenced that mathematics anxiety is positively correlated with with neuroticism also.

7 Conclusion

Chapter 7 Contents

7.1 Purpose of this Research

A. Smith (2017) in their review of post-16 mathematics highlighted that the so-called "mathematics gap" (DfE, 2013) among university students was a likely reason for students experiencing high levels of mathematics anxiety and low levels of confidence when completing mathematics-based tasks. This project aimed to further these findings with four studies conducted at Higher Education institutions which collected data from 605 students across three separate cohorts who had just commenced on their degree courses at university.

To give further evidence for the basis of this research from the perspective of Higher Education, we also attempted to make a case for why university institutions require their students to have quantitative skills. To this effect, we surveyed all 244 first-year modules taught at the University of Essex in the academic year 2022-2023 and illustrated that quantitative elements were listed within the module description of 32% of these, which accounted for 10 of the 18 university departments. The quantitative skills expected of most of these modules involved fundamental skills such as algebra, numeracy and statistics within a range of applied settings such as finance or the interpretation and presentation of data. One may suggest, however, that a quantity of these skills are already taught within the GCSE Mathematics syllabus (see Ofqual GCSE Syllabus) which is reflected by the fact that most university degree courses do not stipulate that students need to have studied mathematics beyond this level (Hodgen et al., 2014). However, we used this research to establish whether students do, indeed, start their undergraduate university courses with this baseline knowledge, or whether further post-16 mathematics qualifications are a necessary requirement to help bridge this gap. As such, we designed our studies with the aim of establishing differences between students who had studied a post-16 mathematics qualification and their counterparts who had only achieved the minimum mathematics qualification necessary to start their course.

7.2 Summary of Our Main Findings

Table 7.0 shows an overview of results from all four surveys. Our findings show that students who had not taken a post-16 mathematics qualification are generally significantly behind the quantitative ability of students who have. In addition - and perhaps more crucially - the majority of studies found that this gap still exists even after one term of studying at university. Therefore students without a post-16 mathematics qualification not only start with lower quantitative knowledge and skills than their counterparts, but one term of university teaching is not enough time for them to gain the necessary quantitative skills which are required meaning that they are still behind. As well as performance accuracy, we also found that students without a post-16 mathematics qualification were generally less confident when completing the mathematics-based tasks and also experienced higher levels of mathematics anxiety.

This research also revealed other important implications. Namely, that participants generally tended to exhibit poorer performance accuracy when completing statistics tasks than numeracy tasks, irrespective of whether they had studied mathematics after the age of 16. This is important to understand further since a large portion of the A-Level Mathematics syllabus has been reformed to include a compulsory statistical element which accounts for approximately 16% of the overall syllabus, including an introduction of a Large Data Set which should give students experience with interpreting real statistical data and investigating patterns and trends (UK Government, 2017). Indeed, one of the features of the set of Core Mathematics qualifications was that they would also include analysing and interpreting data in real-life contexts (DfE, 2013). Our findings could mean that further research is required in this direction in order to look at whether these differences remain true for individual post-16 qualifications, and if so whether the content needs to be strengthened. Reassuringly, however, is that numeracy is generally stronger among participants who have studied a post-16 mathematics qualification. Given that statistical concepts are generally considered to utilise numeracy skills, then it is feasible that specific statistical knowledge can be acquired through targeted intervention at university, although our research broadly seems to suggest that this does not happen within a single term.

One should note, however, that there may be a lack of uniformity in the way that the statistical components of such post-16 qualifications are taught. For example, the Large Data Set is clearly stipulated as an important component of the A-Level Mathematics syllabus that is intended to enrich teaching and understanding of statistical techniques (UK Government, 2017). One could argue, however, that since there are alternative methods to present these statistical ideas and that the assessment questions will only award a small proportion of the marks to questions regarding the Large Data Set (see, for example, the notes and guidance documents from the A-Level Mathematics awarding bodies), it is entirely feasible to do well in A-Level Mathematics without a large amount of consideration towards exploring the Large Data Set. One could make similar arguments towards Core Mathematics. As discussed in Section 3.3.7, very few universities will actively consider Core Mathematics as part of their entry offers which, combined with the fact that it can be taught as a one year qualification, may result in less incentive for students to actively engage within the qualification relative to other A-Level subjects that will form part of their university offer. Thus, whilst the findings presented in our studies may give insight that warrants further exploration, one needs to be mindful that, especially with a smaller sample size, the participants with a post-16 mathematics qualification may have had different levels of engagement which may affect variability in results.

Whilst the investigation into wider quantitative performance at university is not completely unexplored (Mulhern & Wylie, 2004; Durrani & Tariq, 2012; Thompson et al., 2015), this is still a research area which requires additional evidence. In particular, the prior evidence that has been produced by existing studies did not capture the widespread changes to the Secondary and Further Education landscape as a result of Gove's Reforms (see Section 3.1). Alternatively, studies used secondary data such as the National Pupil Database (Adkins & Noyes, 2018) or the Higher Education Statistics Agency (Vidal Rodeiro et al., 2015) which uses existing data about attainment in examinations. Whilst the data in such databases is undoubtedly rich and provides a certain level of insight on a large scale, it is unable to determine specific characteristics such as levels of mathematics anxiety or confidence when completing mathematics-based tasks akin to that seen in our study since it mostly measures outcomes of the qualifications achieved rather than asking students themselves to answer questions. One also needs to consider that this kind of secondary data is collected once a student has completed the qualification and thus can only assess final outcomes as opposed to what happens at the start of studying the qualification or part-way into the term, as captured by our data.

7.3 Key Recommendations

Our evidence allows us to make recommendations in several key directions. Firstly, the UK Government offers several incentives such as the Advanced Mathematics Premium (UK Government, 2023a), the High Value Courses Premium (UK Government, 2023b), the Large Programme Uplift (UK Government, 2023c) and, most recently, the Core Mathematics Premium (UK Government, 2024). These incentives are designed with the aim of encouraging Further Education colleges to offer post-16 mathematics qualifications to their students. However, most of these incentives have been provided based on the widely-held beliefs or opinions from subject-specialists that mathematics is important for students. Whilst this belief might seem logical there is little empirical evidence to show how students without a post-16 mathematics qualification tend to perform against their counterparts for the next step in education i.e., when progressing to university. Our research has provided some evidence in this direction, specifically for students starting at UK universities, with participants who had studied mathematics in the typical 16-18 “mathematics gap” (DfE, 2013) possessing a greater amount of quantitative skills and knowledge that is required for university study. As such, this gives further value in providing these financial incentives to Further Education colleges as a means of encouraging their students to take post-16 mathematics.

Another issue which our research has aimed to address is regarding the messaging given by universities to prospective students. This typically contains very little weighting towards the importance of mathematics study after the age of 16 in preparation for their degree courses (Glaister, 2017b; Lee et al., 2017). Some students have even been reported to be surprised at the level of mathematics content on their degree course (Dawson, 2014). This is despite the handbooks of certain awarding bodies explicitly stating that significant quantitative skills are a necessary component for degree schemes to gain accreditation (Royal Society of Biology (RSB), 2015; The British Psychological Society (BPS), 2019; British Computer Society (BCS), 2022). Indeed, we have not only shown that participants with a post-16 mathematics qualification are more prepared in terms of quantitative skills and knowledge which they are likely to face, but also that their counterparts have higher levels of mathematics anxiety and lower confidence when dealing with mathematics tasks. As such, these factors may cause students without post-16 mathematics to become reluctant to engage with the types of quantitative skills which they will inevitably meet during their degree course. In extreme scenarios, these students may even be likely to withdraw from their course if these feelings of mathematics anxiety and lack of confidence manifest into stress and fear of falling behind, although our study cannot provide explicit evidence that this is the case.

Whilst incentives encourage Further Education schools and colleges to offer a post-16 qualification, one also needs to consider the incentive of the student. For example, Homer et al.

(2020) reported in their interviews with students and teachers that a motivating reason for students wanting to take a qualification is the recognition from universities of its importance. Indeed, some of the elite Russell Group universities previously offered a list of “facilitating subjects” which would recommend certain A-Level subjects as being beneficial for particular degree courses (Russell Group, 2019). However, the messaging regarding Core Mathematics in particular was mixed with some universities providing strong endorsements of the qualification through reduced entry offers (e.g., University of Exeter, University of York, University of Bath, University of Sheffield, Keele University), whilst other universities stating that they would not consider this unless Core Mathematics would be made available to all learners (Glaister, 2017b). Indeed, The Royal Society (2023) published data from 2022 showing that only a third of Further Education schools and colleges had students taking Core Mathematics with as much as 10% of the local authorities in England not having any students who took the qualifications. We must also consider that the numbers of students taking any form of Level 3 mathematics is estimated to be low, especially compared to other countries (Hodgen et al., 2010). Thus, if students do indeed look to university messaging when choosing which post-16 qualifications to take, then more emphasis needs to be placed on the positive messaging surrounding the importance of post-16 mathematics for degree courses. As such, our research provides evidence that post-16 mathematics qualifications are associate with lower levels of mathematics anxiety and higher levels of confidence when completing mathematics-based tasks. In addition, our evidence shows that students with post-16 mathematics start at university already possessing much of the quantitative skills and knowledge required to engage with the content of their respective degree courses. It is reasonable to assume that this level of preparedness aids with transitions into university through positive attitudes towards the required quantitative elements.

7.4 Tool for determining baseline quantitative knowledge at the start of university

As well as providing evidence of differences between students with and without a post-16 mathematics qualification when starting at university, this project has also developed a diagnostic tool which could be used to determine such differences in performance. Many of the numeracy and statistics questions have been specifically designed by the author to align with the key skill areas associated with the quantitative needs of mathematics undergraduates (Hodgen et al., 2014). We also determined this by basing the numeracy questions on a similar tool used by Greer & Semrau (1984) for our first study in 2019-2020. We then developed these questions to suit cohorts of students that would be answering questions in an online environment in 2021-2022 and 2022-2023 by ensuring that questions assessed the ability to make interpretations, deductions or calculations from the given information.

For all of our studies, we aligned the questions to quantitative skill areas which were determined to be important by using statements such as that made by Confederation of British Industry (CBI) (2010) and Rushton & Wilson (2014). We also created the questions so that they could assess differences between cohorts of students with and without a post-16 mathematics qualification, without requiring knowledge of specific mathematics topics that would only have been met beyond GCSE Mathematics. We achieved this by increasing the diversity of mathematics skills that were necessary in order to answer questions with this increased level of difficulty. For instance, Figure C.17a shows a numeracy question which is rated as being a question with increased difficulty and, thus, is aimed at participants with post-16 mathematics. It tests one's ability to determine how the square of the product of two quantities will change when each quantity is increased by a given multiplication factor. Whilst participants who have not studied post-16 mathematics are expected to understand the individual components of the question and the operations being used, they may not be as confident to form an effective strategy, particularly if they have had a two-year gap from studying mathematics. Another illustration of the enhanced level of question difficulty can be seen in Figure B.12a which requires participants to extract information from a few paragraphs of text. This not only requires participants to understand and interpret context from the given information, but it also tests their ability to determine which pieces of information are relevant and how they need to form them into calculations. The multiple-choice options for all questions were also designed based on likely areas which a participant may have made errors. For example, Figure B.13a shows a question whose multiple-choice options were based on the potential of inaccurate time-unit conversions such as converting 150 minutes into 1 hour 50 minutes.

In addition to creating bespoke numeracy and statistics questions, we have also demonstrated that these questions can be used in both an online and lab-based environment. This is best-evidenced in Chapter 6 which used an identical version of the set of questions and instruments, however it was implemented in both types of environments and broadly similar results were found. As such, such a tool could be used to investigate further demographic differences such as geographic location, especially considering that the provisions of some post-16 mathematics qualifications remains lower in certain regions of the UK (The Royal Society, 2023).

Our tool also aims to fulfil some of the statements made in the Smith Review (A. Smith, 2017), particularly regarding students who have not studied mathematics between the ages of 16-18 are less confident and higher in mathematics anxiety. Our study contains instruments that are intended to measure such factors, as well as other factors such as personality traits and attitudes towards mathematics which have been shown to offer insight into academic performance differences.

7.5 Limitations and Scope for Future Research

Whilst our data contained the potential for sub-group analysis such as differences between particular post-16 mathematics qualifications (e.g., Core Mathematics, A-Level Mathematics, IB Mathematics, non-UK mathematics), unfortunately the scale of our sample size meant that our data was not powered enough to find statistically valid conclusions here. However, we did perform visual analysis which demonstrated that the effects due to studying post-16 mathematics appeared to also hold within the individual qualifications. In particular, for all of our studies apart from the 2022-2023 Lab-based Study, Core Mathematics appeared to be only marginally behind the performance levels of participants with other post-16 qualifications. It should be noted, however, that the 2022-2023 Lab-based Study suggested that participants with post-16 mathematics appeared to perform worse.

We acknowledge that our method of classifying participants as having *high* or *low* levels of mathematics on the basis of whether they had studied a post-16 mathematics qualification or not, whilst simple, could lead to a lack of homogeneity within these comparison groups. Namely, our current method would classify a participant who had achieved a high grade in A-Level Mathematics and Further Mathematics in the same group as a participant who had obtained a low grade in Core Mathematics, simply because both participants had studied a mathematics qualification after the age of 16. However, a motivation for conducting our research was in response to the so-called “mathematics gap” (DfE, 2013) and to explore its effects for transitions to university. Indeed, this meant that we aimed to investigate whether there was a case for choosing a mathematics qualification as a post-16 option in general, rather than exploration into specific qualifications and grades. Further subgroup analysis may reveal deeper understanding of the trends and differences that we found, however we also feel that this would require larger sample sizes across multiple university institutions in order to report these with confidence. As a form of preliminary investigation, however, we feel that the work that we have presented is a good starting point.

There is also the potential for further exploration within the data that we collected. Namely, we did not focus on differences within the subscales of the numeracy and statistics questions such as calculation, estimation or reasoning. Indeed, the fact that performance on the statistics questions remained largely weak for all participants may suggest that such subscale analysis may lead to interesting conclusions. Our data is also unique in that it captures a snapshot from a period in Higher Education before, during and after the COVID-19 pandemic which clearly cannot be replicated within similar studies in the future. Given the similarity in many of the questions and instruments which we used across all of our studies, there could be further exploration using our data into the changes caused by COVID-19 giving additional insights in a way that other similar studies could not replicate. The 2019-2020 Study was not pre-registered and we stated that data would be used by research assistants and collaborators involved in the study. As such, this data cannot be published or made publicly available. The data collected from the 2021-2022 Study and the 2022-2023 Study were both pre-registered and we explicitly stated within our ethics approval and when obtaining consent from participants that anonymised data would be published.

We attempted to explore how our measured variables could predict numeracy and statistics performance using path analysis models. Whilst this was intended to offer further insight in addition to the differences and correlations found in the primary and secondary analysis, we used them as a predictive modelling technique rather than to infer underlying causal relationships. This means that our models can be used to illustrate associations between variables such as confidence, mathematics anxiety, and mathematics and statistics performance, however it cannot prove influence. In order to achieve this, one would need to conduct a larger sample size from a greater variety of institutions whilst controlling for more demographic factors that could affect mathematics and statistics performance such as family attitudes towards mathematics and consideration over the amount of engagement with the mathematics content of qualifications.

7.6 Final Remarks

One obvious question to ask in response to our findings is whether universities should now say that post-16 mathematics qualifications should now be made compulsory for prospective students looking to apply to their courses. Certainly, such bold statements would unearth additional and more complex issues involving recruitment of students to university as well as the provision of qualified teaching staff who could facilitate these Level 3 mathematics qualifications. However, more recognition could be made of the usefulness of these qualifications to prepare students for their courses. Thus, whilst our research is not designed as a basis to push universities into changing their stance on post-16 mathematics, we certainly hope that the evidence provided in this project is of value to aid with recognising the value of them and will help when creating statements about entry requirements which are advertised to prospective students.

Another basis of conducting this research was in the wake of the Government-commissioned Smith Review (A. Smith, 2017) where our findings supported many of the statements made here from the perspective of Higher Education. Indeed, the issue of post-16 mathematics became even more topical whilst conducting this research with several statements being made by the Prime Minister, Rishi Sunak, about ambitions to make post-16 mathematics available to an increased number of learners in Further Education (UK Government, 2023e). As such, one hopes that our results can contribute in some way towards the argument that post-16 mathematics qualifications are indeed beneficial for reducing mathematical anxiety and building confidence when working with mathematics-based tasks. In addition, we are confident that our results prove that having a post-16 mathematics qualification is an effective way of easing the transition between Further and Higher Education by ensuring that learners are equipped with the key quantitative skills required for university study. Indeed, with the recent development of post-16 mathematics qualifications such as Core Mathematics, this makes accessing Level 3 mathematics possible for a greater number of students. If universities are also able to endorse this by using our work as a basis for this recognition then the numbers of students taking post-compulsory mathematics could indeed be expected to increase.

Table 7.0 | Summary of results for performance accuracy, confidence judgments and mathematics anxiety ratings for all four studies: sample sizes, medians, standard deviations, Wilcoxon test statistics, *p*-values, 95% confidence intervals, and effect sizes.

			With Post-16 Mathematics		Without Post-16 Mathematics		*W*	*p*-value	95%CI		Effect Size
			n	Median (SD)	n	Median (SD)			Lower	Upper	
Numeracy Performance	Pre-test	Study 1	118	6 (2.2)	120	3 (1.9)	10456	<0.001	2.000	3.000	0.921
		Study 2	55	12 (2.9)	64	9 (2.8)	2469.5	<0.001	1.000	3.000	0.699
		Study 3	72	5 (2.1)	60	3 (1.5)	1286	<0.001	-2.000	-1.000	-0.764
		Study 4	83	7 (1.6)	33	4 (1.9)	561	<0.001	-3.000	-2.000	-1.249
	Post-test	Study 1	59	6 (2)	47	3 (2)	2217.5	<0.001	2.000	3.000	1.121
		Study 2	25	10 (2.1)	30	7 (2.7)	573.5	<0.001	1.000	4.000	1.000
		Study 3	35	4 (2.1)	26	4 (1.4)	390	1.0000	-2.000	1.000	-0.291
		Study 4	73	6 (1.6)	25	5 (1.7)	720.5	1.0000	-2.000	0.000	-0.399
	Pre-/Post-test	Study 1	34	0 (1.2)	38	0 (1.4)	602.5	0.4689	-1.000	0.000	-0.153
		Study 2	25	-2 (1.6)	30	-1 (2.8)	332	0.4665	-2.000	1.000	-0.249
		Study 3	35	-1 (1.2)	26	1 (1.5)	639.5	0.1435	0.000	2.000	0.736
		Study 4	73	-1 (2.1)	25	0 (2.2)	1262	0.0945	0.000	2.000	0.721
Statistics Performance	Pre-test	Study 1	118	5 (1.6)	120	5 (1.6)	76035	0.3013	0.000	1.000	0.139
		Study 2	55	10 (2.8)	64	8 (2.2)	2121.5	0.0527	0.000	2.000	0.338
		Study 3	72	4 (1.9)	60	4 (1.4)	1793	0.0868	-1.000	0.000	-0.423
		Study 4	83	6 (1.7)	33	4 (1.8)	626.5	<0.001	-3.000	-1.000	-1.025
	Post-test	Study 1	59	5 (1.5)	47	5 (2.1)	1492	0.6310	-1.000	1.000	0.135
		Study 2	25	10 (3)	30	7 (2.7)	569	0.0212	1.000	5.000	0.961
		Study 3	35	5 (1.7)	26	4 (1.4)	319	1.0000	-2.000	0.000	-0.530
		Study 4	73	6 (1.4)	25	6 (1.3)	761	1.0000	-1.000	0.000	-2.110
	Pre-/Post-test	Study 1	34	0 (1.3)	38	0 (1.8)	667	0.9955	-1.000	1.000	-0.037
		Study 2	25	-1 (2.1)	30	-2 (2.3)	451.5	0.1936	0.000	2.000	0.340
		Study 3	35	0 (1.5)	26	0 (1.3)	468.5	0.8466	-1.000	1.000	0.048
		Study 4	73	0 (2)	25	1 (1.6)	1261	0.0947	0.000	2.000	0.643
Overall Performance	Pre-test	Study 1	118	11 (3.1)	120	8 (2.9)	9866	<0.001	2.000	3.000	0.701
		Study 2	55	21 (5.2)	64	17 (4.1)	2403.5	<0.001	1.000	5.000	0.604
		Study 3	72	9 (3.5)	60	7 (2.5)	1420	<0.001	-3.000	-1.000	-0.681
		Study 4	83	12 (2.9)	33	8 (3.1)	504.5	<0.001	-6.000	-3.000	-1.310
	Post-test	Study 1	59	12 (2.8)	47	8 (3.5)	2024	<0.01	1.000	4.000	0.798
		Study 2	25	20 (4.7)	30	13.5 (4.6)	585.5	<0.01	3.000	8.000	1.113
		Study 3	35	9 (3.5)	26	8 (2.2)	345.5	0.1099	-3.000	0.000	-0.460
		Study 4	73	11 (2.7)	25	10 (2.8)	721	0.1159	-2.000	0.000	-0.342
	Pre-/Post-test	Study 1	34	0 (1)	38	0.25 (1.2)	637	0.7504	-0.500	0.500	-0.114
		Study 2	25	-1.5 (1.4)	30	-1.75 (1.8)	400	0.6770	-0.500	1.000	0.047
		Study 3	35	0 (0.9)	26	0.5 (1)	612	0.2662	0.000	1.000	0.541
		Study 4	73	-0.5 (1.8)	25	1 (1.6)	1331	<0.01	0.500	2.000	0.769
Confidence	Pre-test	Study 1	118	7.75 (1.7)	120	6.06 (1.9)	9771.5	<0.001	0.813	1.812	0.675
		Study 2	55	3.1 (0.6)	64	2.4 (0.5)	2478.5	<0.01	0.233	0.667	0.683
		Study 3	72	2.84 (0.7)	60	2.56 (0.6)	1570.5	0.0920	-0.562	-0.125	-0.460
		Study 4	83	3.12 (0.5)	33	2.69 (0.5)	800	<0.01	-0.625	-0.187	-0.754
	Post-test	Study 1	59	7.81 (1.7)	47	6.69 (2.1)	1751.5	0.0359	0.062	1.625	0.457
		Study 2	25	3.13 (0.6)	30	2.53 (0.5)	547.5	0.0363	0.167	0.767	0.697
		Study 3	35	2.94 (0.6)	26	2.56 (0.5)	296	0.4968	-0.688	-0.063	-0.604
		Study 4	73	3.12 (0.5)	25	2.88 (0.6)	694	1.0000	-0.438	0.000	-0.410
	Pre-/Post-test	Study 1	34	0.25 (1.4)	38	-0.12 (1.2)	652	1.0000	-0.500	0.375	-0.183
		Study 2	25	0.1 (0.3)	30	0.05 (0.4)	329.5	1.0000	-0.233	0.100	-0.305
		Study 3	35	0.12 (0.6)	26	-0.12 (0.5)	393.5	1.0000	-0.313	0.125	-0.182
		Study 4	73	0.19 (0.6)	25	-0.19 (0.5)	934	1.0000	-0.188	0.250	0.067
Mathematics Anxiety	Pre-test	Study 1	118	2.12 (0.8)	120	2.54 (0.8)	5349.5	0.0145	-0.615	-0.154	-0.424
		Study 2	55	2 (0.9)	64	2.62 (0.9)	1240	0.0560	-0.846	-0.154	-0.475
		Study 3	72	2.15 (0.8)	60	2.92 (0.8)	3025	<0.01	0.308	0.923	0.711
		Study 4	83	2 (0.7)	33	2.46 (0.9)	1750.5	0.2573	0.077	0.692	0.533
	Post-test	Study 1	59	2.15 (0.8)	47	2.46 (0.8)	1105	0.0516	-0.615	0.000	-0.308
		Study 2	25	2 (0.7)	30	2.58 (0.9)	232	0.3337	-1.000	-0.077	-0.664
		Study 3	35	2.23 (0.8)	26	3 (0.9)	713	<0.01	0.462	1.385	1.098
		Study 4	73	2 (0.7)	25	2.15 (0.8)	1008.5	1.0000	-0.154	0.462	0.271
	Pre-/Post-test	Study 1	34	0 (0.5)	38	0.15 (0.6)	600.5	1.0000	-0.308	0.154	-0.118
		Study 2	25	0 (0.5)	30	0.12 (0.5)	284	1.0000	-0.462	0.077	-0.400
		Study 3	35	0 (0.8)	26	0.15 (0.5)	520.5	1.0000	-0.154	0.462	0.127
		Study 4	73	-0.23 (0.9)	25	-0.08 (0.9)	983	1.0000	-0.231	0.385	0.037

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A Questions Used in the 2019-2020 Study

Appendix A Contents

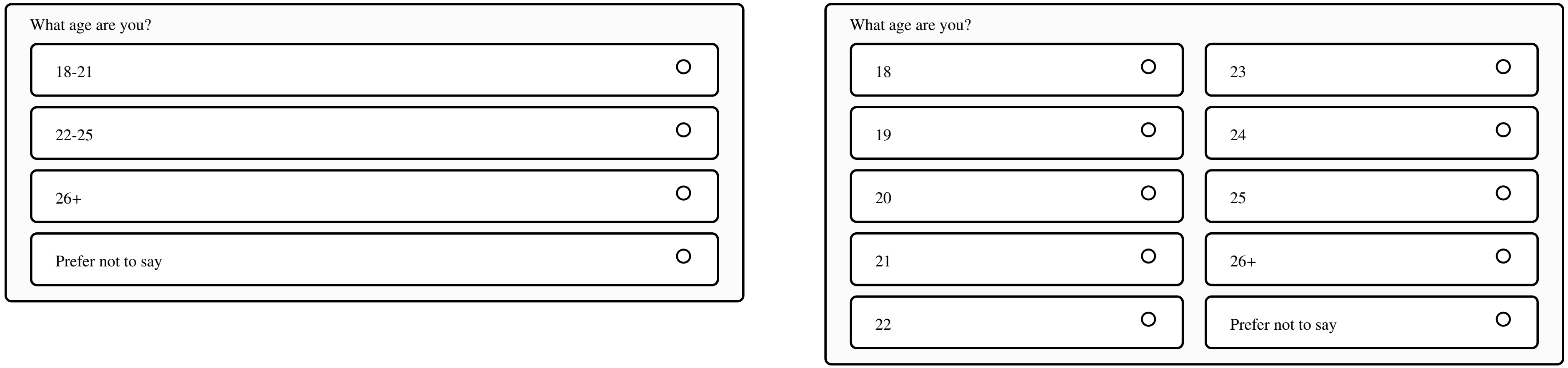
A.1 Demographic Questions

This subsection shows the demographic questions that were used in the 2019-2020 study. The questions attempted to determine basic information such as age, gender and their education backgrounds. Since the focus of this research looked at post-16 mathematics experience, the demographic questions were also designed to establish whether a participant was studying in the UK between the ages of 16-18 as well as whether they studied a post-16 mathematics or statistics qualification. In the case of both of these questions being answered *Yes*, participants were then asked to indicate which post-16 mathematics qualification they took. Due to the wide variety of non-UK post-16 mathematics qualifications, no further education questions were asked to non-UK participants.

Please type the name of your degree scheme in the box below.

For example, Psychology.

Figure A.1 | First demographic question to determine a participant's degree scheme.



(a) Question shown at the pre-test

(b) Question shown at the post-test.

Figure A.2 | Second demographic question to determine a participant's age. For the pre-test we asked participants to categorise their ages according to the age brackets that undergraduates tend to fall in UK Higher Education, namely: *18-21*=participants who entered university soon after finishing education; *22-25*=participants who had a short break from education and are now returning; *26+*=participants who are considered mature students and who have had a long break from education. For the post-test we decided to be more specific and asked participants to categorise their specific age.

To which gender do you most identify?

- Male
- Female
- Other
- Prefer not to say

Figure A.3 | Third demographic question to determine a participant's gender.

Did you study post-16 education in England, Wales or Northern Ireland?

- Yes
- No

Figure A.4 | Third demographic question to determine where a participant studied between the ages of 16-18. Participants who selected *Yes* were classified as *UK participants*, whereas participants who selected *No* were classified as *non-UK participants*. Note that this question does not stipulate Scotland since they use a different education system to the rest of the UK (see Section D.1.3), so for the purposes of this study, participants from Scotland were classified as *non-UK participants*.

Did you study a mathematics or statistics qualification between the ages of 16-18?

- Yes
- No

Figure A.5 | Fifth demographic question to determine a whether a participant studied a mathematics or statistics qualification between the ages of 16-18.

Which of the following mathematics or statistics qualifications have you studied?

Select all that apply.

Level 3 Core Mathematics ○	A-Level Statistics ○
AS-Level Mathematics ○	IB Maths Studies SL ○
A-Level Mathematics ○	IB Mathematics SL ○
AS-Level Further Mathematics ○	IB Mathematics HL ○
A-Level Further Mathematics ○	IB Further Mathematics HL ○
AS-Level Statistics ○	None of the above ○

Figure A.6 | Sixth demographic question to determine which mathematics or statistics qualifications a participant studied between the ages of 16-18. This question was only asked to participants who had selected *Yes* to the question in Figure A.4 and *Yes* to the question in Figure A.5 i.e., participants who were from the UK and who had studied a post-16 mathematics qualification.

Did you study/are you studying a foundation year at university?

Yes ○	No ○

Figure A.7 | Seventh demographic question to determine whether a participant stuied a foundation year at university.

A.2 Numeracy Questions

This subsection shows the numeracy questions that were used in the 2019-2020 study.

Difficulty: Level 1	**Subscales:** Calculation

What is 17.5% of 80?

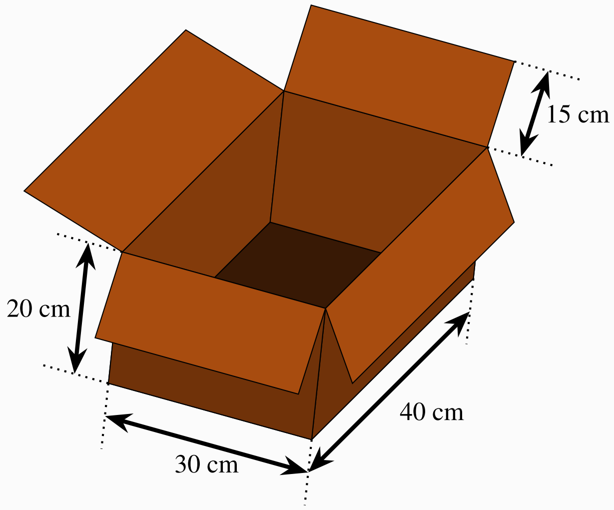
- 12
- 1400
- 97.5
- 14

Figure A.8 | Numeracy question 1

Difficulty: Level 2	**Subscales:** Calculation

The diagram shows a cardboard box that has a width of 30 cm, a length of 40 cm and a height of 20 cm.

There are flaps on the top and bottom which each have a width of 15 cm as shown.

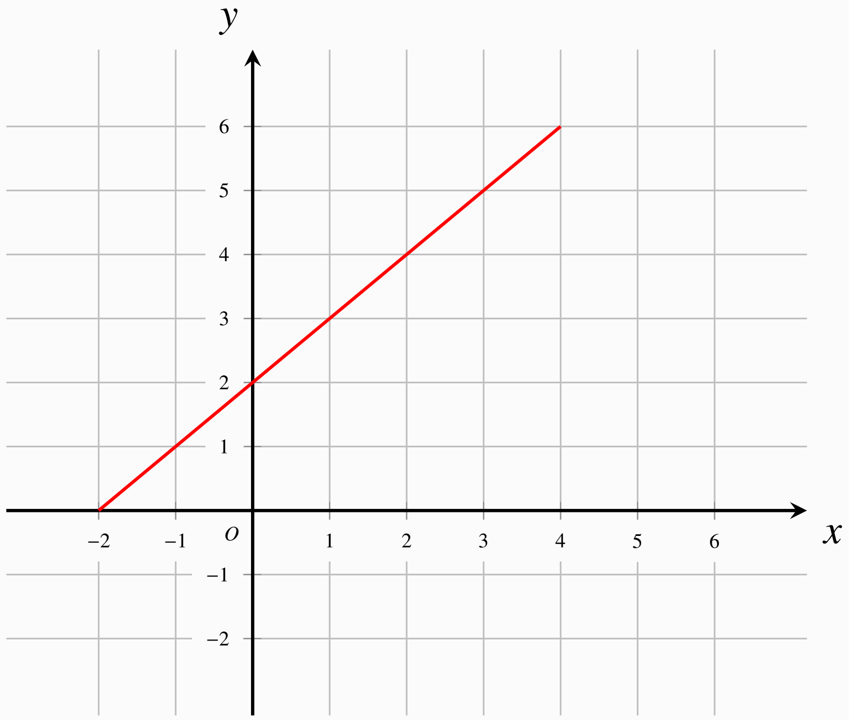


Find the surface area of the cardboard needed to make this box.

- 7000 cm^2
- 2800 cm^2
- 360 000 cm^2
- 4900 cm^2

Figure A.9 | Numeracy question 2

Difficulty: Level 1	**Subscales:** Algebra



Find the equation of the line.

- $y = 2x$
- $y = x$
- $y = 2x + 1$
- $y = x + 2$

Figure A.10 | Numeracy question 3

Difficulty: Level 1	**Subscales:** Conversions

Which of the following is equivalent to 2 : 5?

- 5 : 2
- 0.4 (highlighted as correct)
- 25%
- $\frac{2}{7}$

Figure A.11 | Numeracy question 4

Difficulty: Level 1	**Subscales:** Calculation

Find 3^0

- 30
- 0
- 1 (highlighted as correct)
- 3

Figure A.12 | Numeracy question 5

Difficulty: Level 1	**Subscales:** Calculation

Find 2^4

- 24 ○
- 8 ○
- 6 ○
- 16 ○

Figure A.13 | Numeracy question 6

Difficulty: Level 2	**Subscales:** Conversions

How many square millimetres (mm^2) are there in 1 square metre (1 m^2)?

- 1000 mm^2 ○
- 10 000 mm^2 ○
- 100 000 mm^2 ○
- 1 000 000 mm^2 ○

Figure A.14 | Numeracy question 7

Difficulty: Level 1 | **Subscales:** Calculation

Find the product of 8 and 2

- 16
- 10
- 8
- 6

Figure A.15 | Numeracy question 8

Difficulty: Level 1 | **Subscales:** Calculation

Find $\frac{2}{3} + \frac{3}{4}$

- $\frac{6}{12}$
- $\frac{5}{7}$
- $\frac{17}{12}$
- $\frac{17}{24}$

Figure A.16 | Numeracy question 9

Difficulty: Level 1	**Subscales:** Calculation

Find 6×-3

- 18
- −3
- −18
- −9

Figure A.17 | Numeracy question 10

Difficulty: Level 1	**Subscales:** Conversions

Convert $\frac{1}{8}$ to a decimal

- 0.8
- 1.8
- 0.125
- 0.18

Figure A.18 | Numeracy question 11

Difficulty: Level 1	**Subscales:** Conversions

Which of these is the smallest:

$$0.001 \qquad \frac{1}{10} \qquad 10^{-4} \qquad 1\% \text{ of } 1$$

- 0.001 ○
- $\frac{1}{10}$ ○
- 10^{-4} ○
- 1% of 1 ○

Figure A.19 | Numeracy question 12

Difficulty: Level 1	**Subscales:** Calculation

Find $7 - -2$

- 5 ○
- −5 ○
- 9 ○
- −9 ○

Figure A.20 | Numeracy question 13

Difficulty: Level 1	**Subscales:** Calculation

Find the sum of 9 and 3

- 6
- 12
- 27
- 3

Figure A.21 | Numeracy question 14

Difficulty: Level 2	**Subscales:** Estimation

Find 60 ÷ 0.15

- 400
- 40
- 0.04
- 0.004

Figure A.22 | Numeracy question 15

Difficulty: Level 2	**Subscales:** Estimation

Find 0.03×0.4

- 1.2
- 0.12
- 0.012
- 0.0012

Figure A.23 | Numeracy question 16

Difficulty: Level 2	**Subscales:** Estimation

Find $\sqrt{0.04}$

- 2
- 0.2
- 0.02
- 0.002

Figure A.24 | Numeracy question 17

Difficulty: Level 1	**Subscales:** Algebra

Expand $x(x + 2)$

- ○ $3x$
- ○ $x^2 + 2$
- ○ $2x + 2$
- ○ $x^2 + 2x$

Figure A.25 | Numeracy question 18

Difficulty: Level 1	**Subscales:** Algebra

Solve $2x - 4 = 12$

- ○ $x = 8$
- ○ $x = 4$
- ○ $x = 16$
- ○ $x = 32$

Figure A.26 | Numeracy question 19

Difficulty: Level 2	**Subscales:** Calculation

a and *b* are two numbers. If *a* and *b* are both doubled, how many times will $(ab)^2$ increase?

- 2 times ○
- 4 times ○
- 8 times ○
- 16 times ○

Figure A.27 | Numeracy question 20

A.3 First 30 Personality Items

This subsection shows the first 30 personality items of the Big Five Inventory-2 (BFI-2) that were used in the 2019-2020 study. Since personality traits are considered to be stable and would not change between the pre-test and the post-test, the BFI-2 instrument was used at the pre-test only. We decided to split the personality items to aid with participants' focus and attention rather than answering all 60 items at once.

Table A.1 | The first 30 items of the Big Five Inventory-2 (BFI-2) used to measure personality traits.

The Big Five Inventory-2 (BFI-2) - First 30 items

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please rate each statement to indicate the extent to which you agree or disagree with that statement.

1=Disagree strongly 2=Disagree a little 3=Neutral; no opinion 4=Agree a little 5=Agree strongly

1. I am someone who is outgoing, sociable.
2. I am someone who is compassionate, has a soft heart.
3. I am someone who tends to be disorganised.
4. I am someone who is relaxed, handles stress well.
5. I am someone who has few artistic interests.
6. I am someone who has an assertive personality.
7. I am someone who is respectful, treats others with respect.
8. I am someone who tends to be lazy.
9. I am someone who stays optimistic after experiencing a setback.
10. I am someone who is curious about many different things.
11. I am someone who rarely feels excited or eager.
12. I am someone who tends to find fault with others.
13. I am someone who is dependable, steady.
14. I am someone who is moody, has up and down mood swings.
15. I am someone who is inventive, finds clever ways to do things.
16. I am someone who tends to be quiet.
17. I am someone who feels little sympathy for others.
18. I am someone who is systematic, likes to keep things in order.
19. I am someone who can be tense.
20. I am someone who is fascinated by art, music, or literature.
21. I am someone who is dominant, acts as a leader.
22. I am someone who starts arguments with others.
23. I am someone who has difficulty getting started on tasks.
24. I am someone who feels secure, comfortable with self.
25. I am someone who avoids intellectual, philosophical discussions.
26. I am someone who is less active than other people.
27. I am someone who has a forgiving nature.
28. I am someone who can be somewhat careless.
29. I am someone who is emotionally stable, not easily upset.
30. I am someone who has little creativity.

A.4 Statistics Questions

This subsection shows the statistics questions that were used in the 2019-2020 study.

Difficulty: Level 2	**Subscales:** Calculation

60 students sit a test. The students are divided into two groups.

The mean mark of the 20 students in group A is 30

The mean mark of group B is 45

What is the mean mark of all 60 students?

- 40 ○
- 15 ○
- 75 ○
- 80 ○

Figure A.28 | Statistics question 1

Difficulty: Level 2	**Subscales:** Estimation

The table below shows data about transactions made by a clothing retailer.

	Type of Transaction			
	Online	**Mail Order**	**Telephone**	**In-Store**
Total number of transactions (in thousands)	40	3	12	60
Average number of items purchased per transaction	13	6	2	9
Percentage of transactions from repeat customers	45%	84%	65%	22%

Approximately how many online transactions were from repeat customers?

- 6
- 17
- 17 000
- 220 000

Figure A.29 | Statistics question 2

Difficulty: Level 1	**Subscales:** Estimation

The table below shows data about transactions made by a clothing retailer.

	Type of Transaction			
	Online	**Mail Order**	**Telephone**	**In-Store**
Total number of transactions (in thousands)	40	3	12	60
Average number of items purchased per transaction	13	6	2	9
Percentage of transactions from repeat customers	45%	84%	65%	22%

Approximately how many items were bought in-store?

- 60
- 540
- 60 000
- 540 000

Figure A.30 | Statistics question 3

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The table below shows data about transactions made by a clothing retailer.

	Type of Transaction			
	Online	**Mail Order**	**Telephone**	**In-Store**
Total number of transactions (in thousands)	40	3	12	60
Average number of items purchased per transaction	13	6	2	9
Percentage of transactions from repeat customers	45%	84%	65%	22%

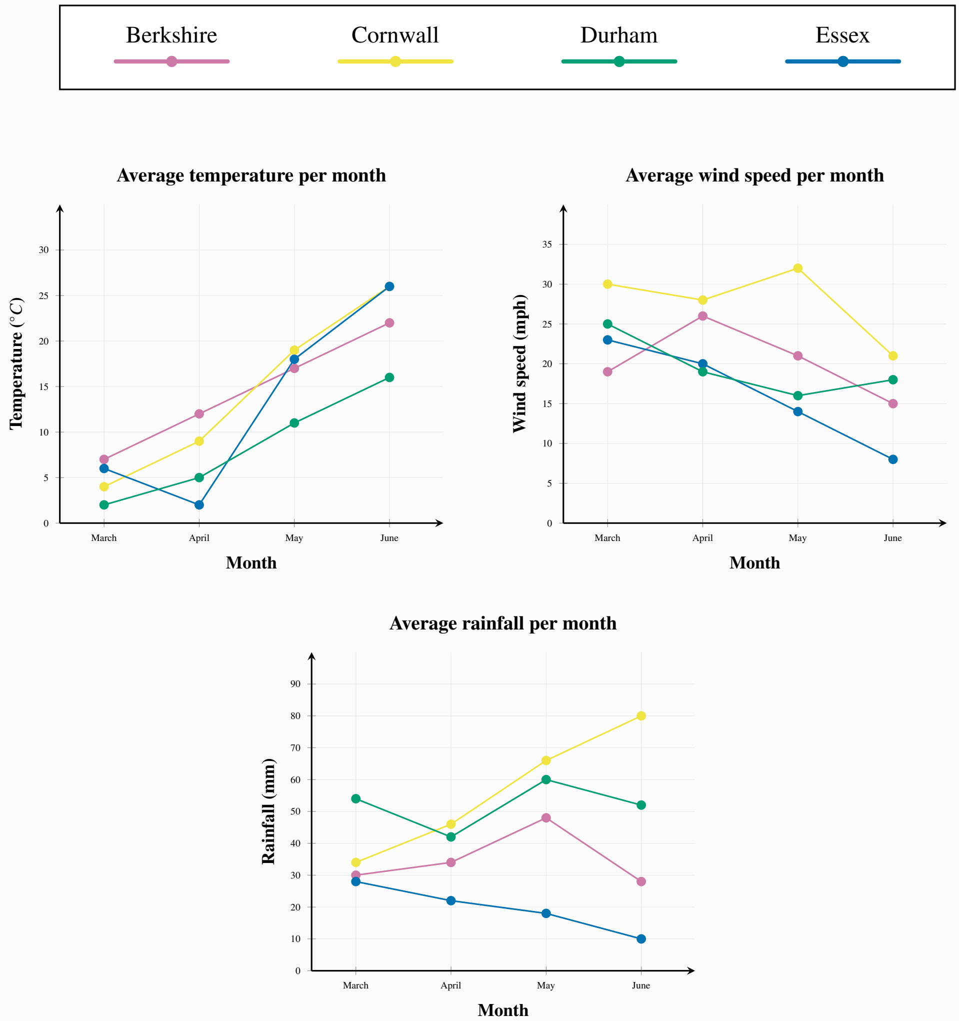
What was the most popular method of purchasing items?

- Online
- Mail Order
- Telephone
- In-Store

Figure A.31 | Statistics question 4

Difficulty: Level 2	**Subscales:** Estimation

The graphs below show weather data from four counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



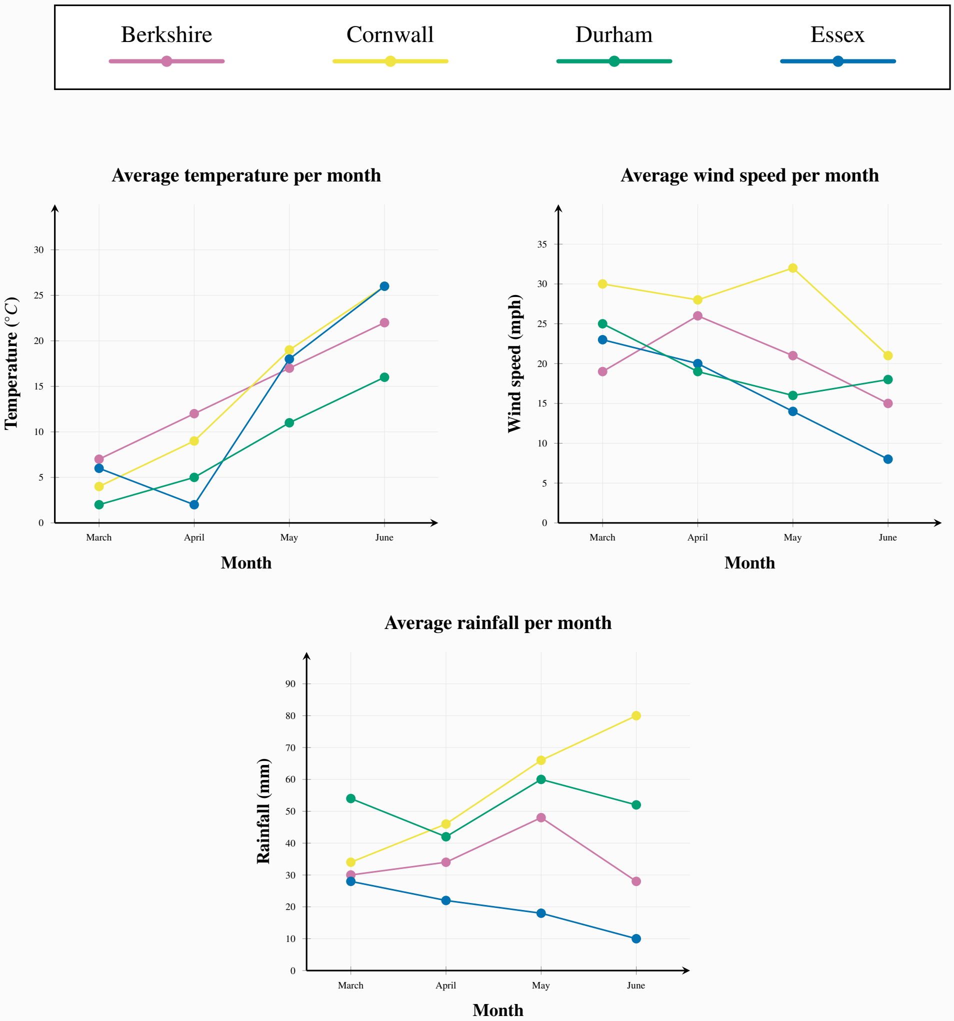
What was the average wind speed between March and June for Cornwall?

- 15 mph
- 23 mph
- 28 mph
- 33 mph

Figure A.32 | Statistics question 5

Difficulty: Level 1	**Subscales:** Calculation

The graphs below show weather data from four counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



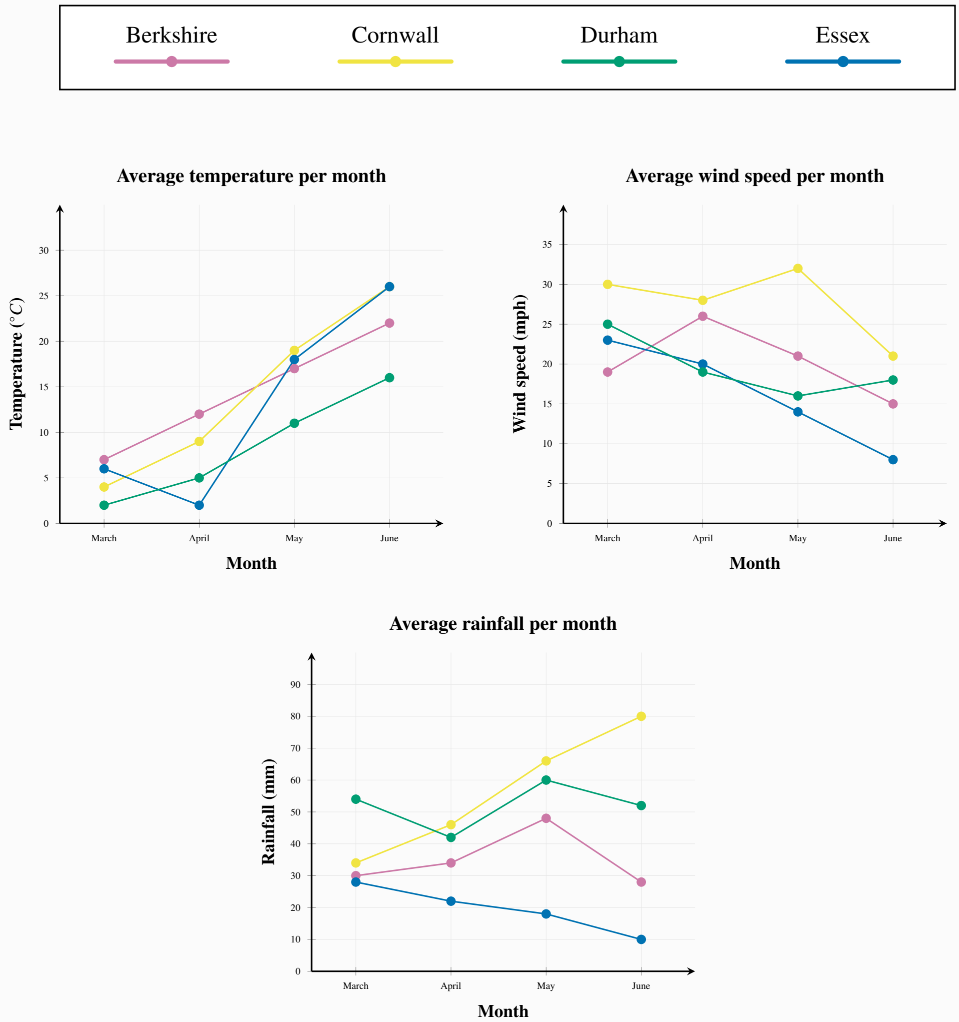
How much more rain did Cornwall get than Essex, on average, during June?

- 10 mm
- 70 mm
- 80 mm
- 90 mm

Figure A.33 | Statistics question 6

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The graphs below show weather data from four counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



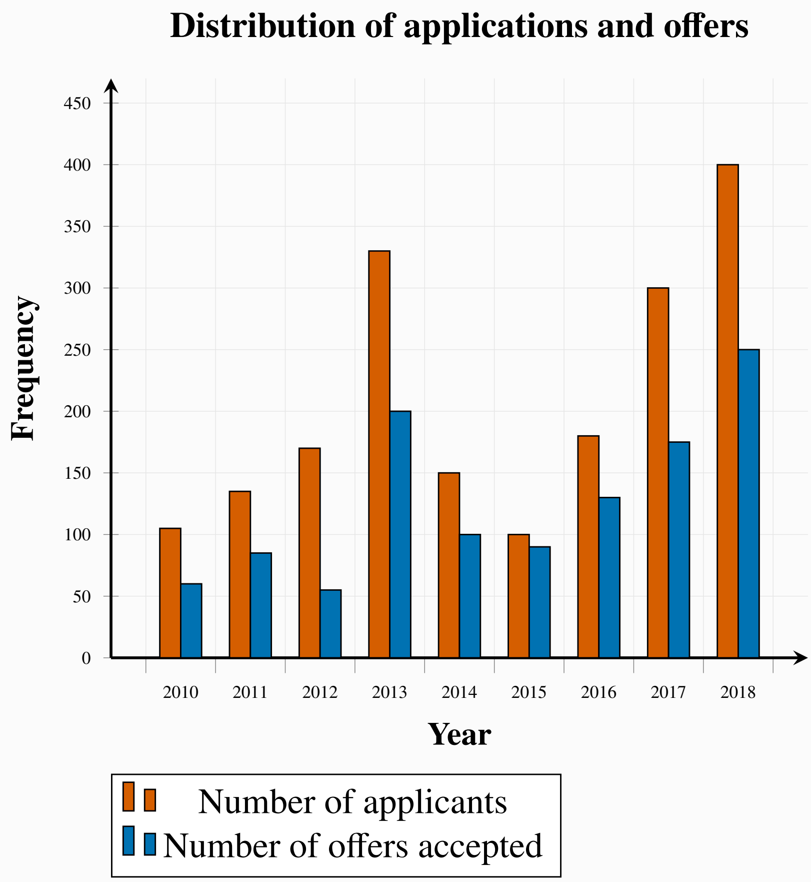
Which county had the biggest difference in temperature during the four-month period?

- Berkshire ○
- Cornwall ○
- Durham ○
- Essex ○

Figure A.34 | Statistics question 7

Difficulty: Level 1	**Subscales:** Calculation

A university department is looking at the applicant data for a particular degree scheme. The graph below shows the number of applicants to the degree scheme and the number of offers which were accepted between the years 2010 to 2018.



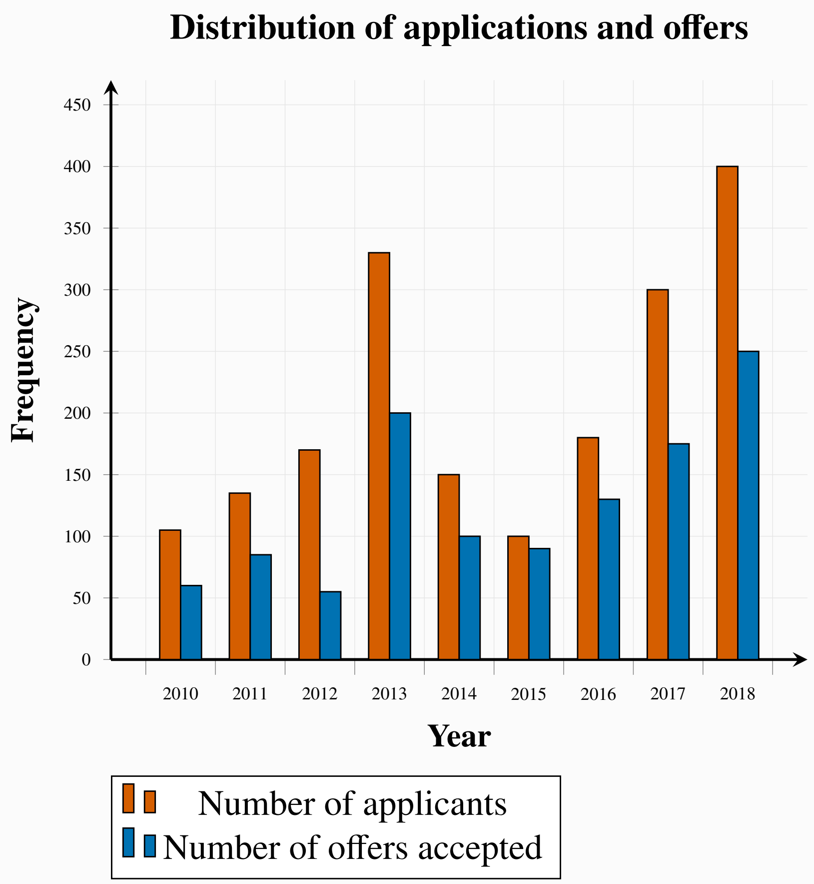
How many more applicants were there in 2018 than 2014?

- 100
- 150
- 250
- 400

Figure A.35 | Statistics question 8

Difficulty: Level 2	**Subscales:** Statistical Reasoning

A university department is looking at the applicant data for a particular degree scheme. The graph below shows the number of applicants to the degree scheme and the number of offers which were accepted between the years 2010 to 2018.



The university department aims to have at least half of its applicants accepting their offers.

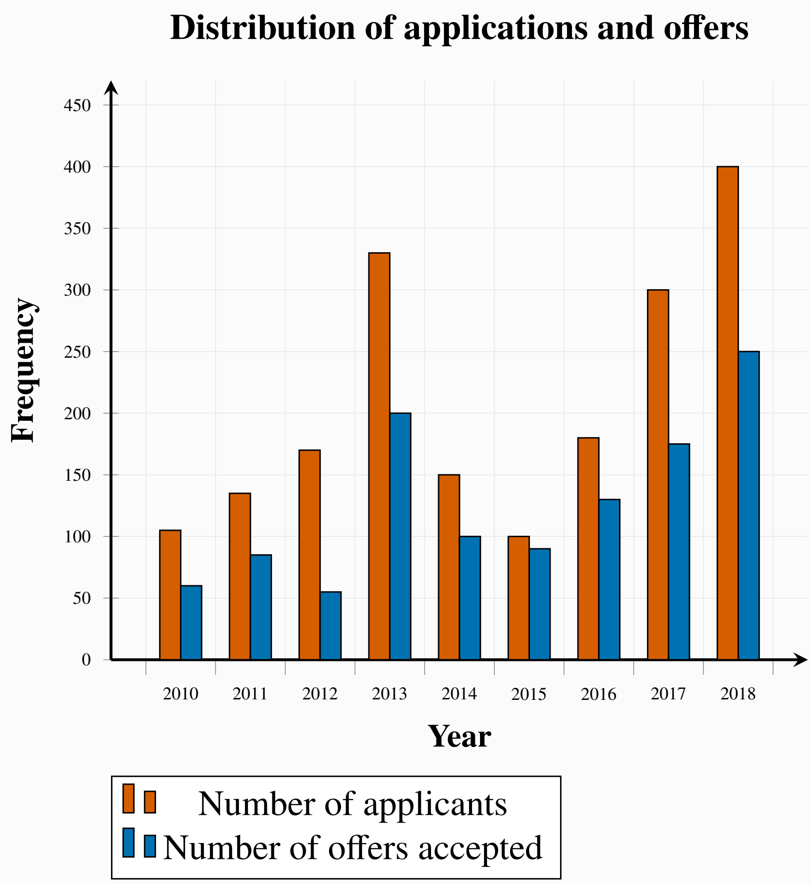
In which year did this degree scheme **fail** to reach the university department's target?

2010 ○	2013 ○	2016 ○
2011 ○	2014 ○	2017 ○
2012 ○	2015 ○	2018 ○

Figure A.36 | Statistics question 9

Difficulty: Level 2	**Subscales:** Statistical Reasoning

A university department is looking at the applicant data for a particular degree scheme. The graph below shows the number of applicants to the degree scheme and the number of offers which were accepted between the years 2010 to 2018.



Which year had the **highest percentage** of applicants accepting their offers?

2010 ○	2013 ○	2016 ○
2011 ○	2014 ○	2017 ○
2012 ○	2015 ○	2018 ○

Figure A.37 | Statistics question 10

Difficulty: Level 2	**Subscales:** Estimation

30 fish were caught in a pond; each one was tagged and then released.

The next day, 50 fish were caught and 10 were found to have tags on.

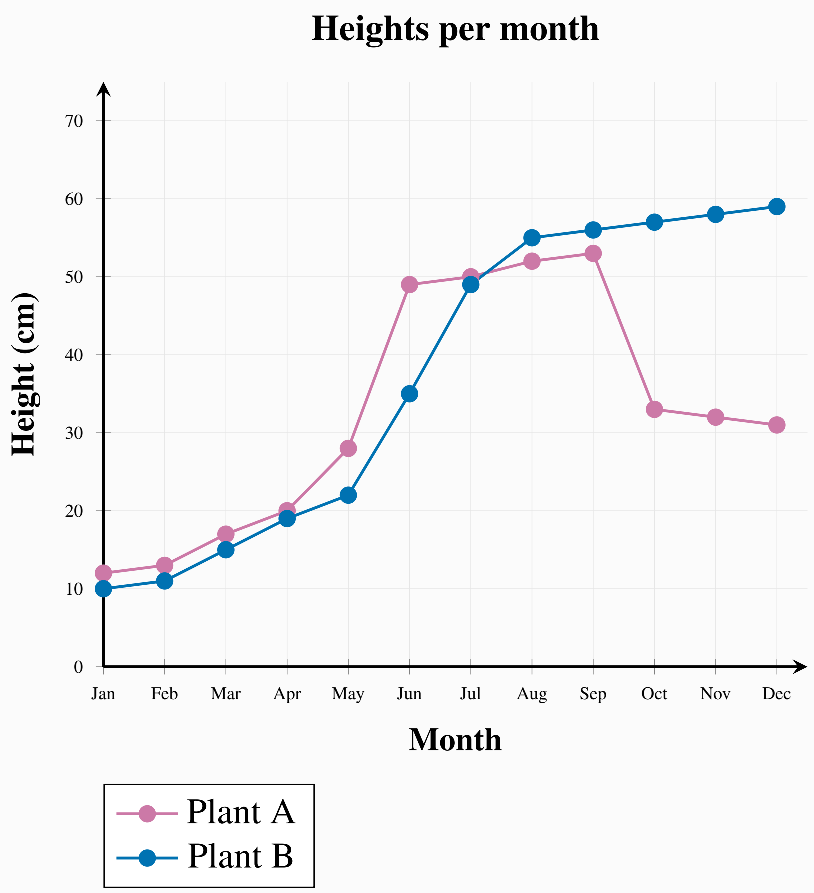
Estimate the total number of fish in the pond.

- 150
- 70
- 200
- 120

Figure A.38 | Statistics question 11

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The heights of two plants, Plant A and Plant B, were measured at the start of every month. Here is the graph of their growth:



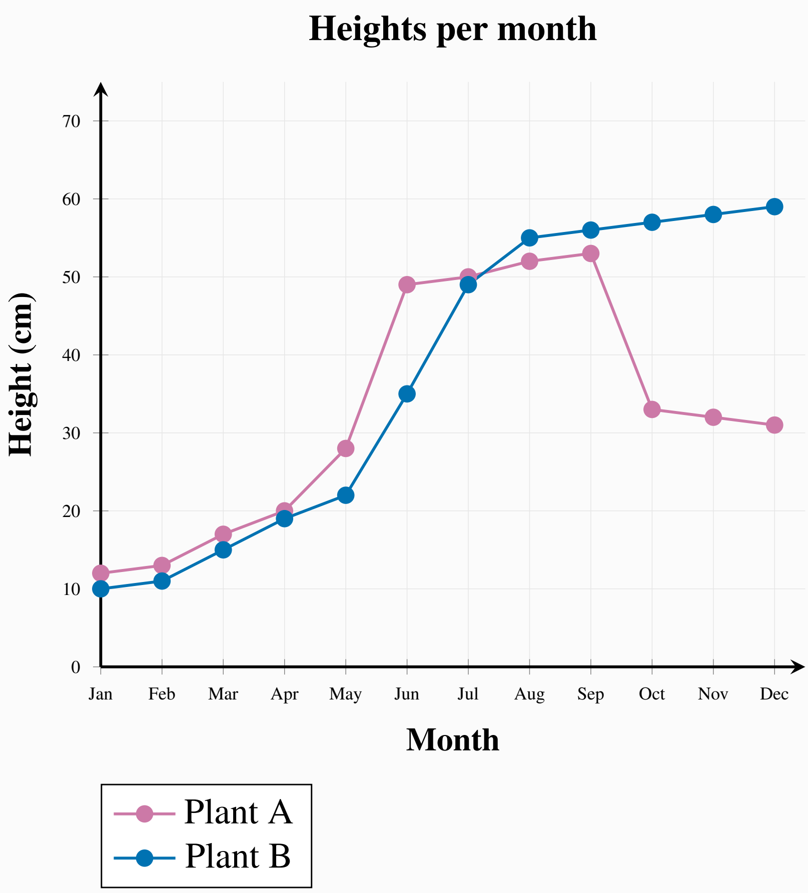
During which month did **Plant A** grow the fastest?

Jan ○	Apr ○	Jul ○	Oct ○
Feb ○	May ○	Aug ○	Nov ○
Mar ○	Jun ○	Sep ○	Dec ○

Figure A.39 | Statistics question 12

Difficulty: Level 1	**Subscales:** Calculation

The heights of two plants, Plant A and Plant B, were measured at the start of every month. Here is the graph of their growth:



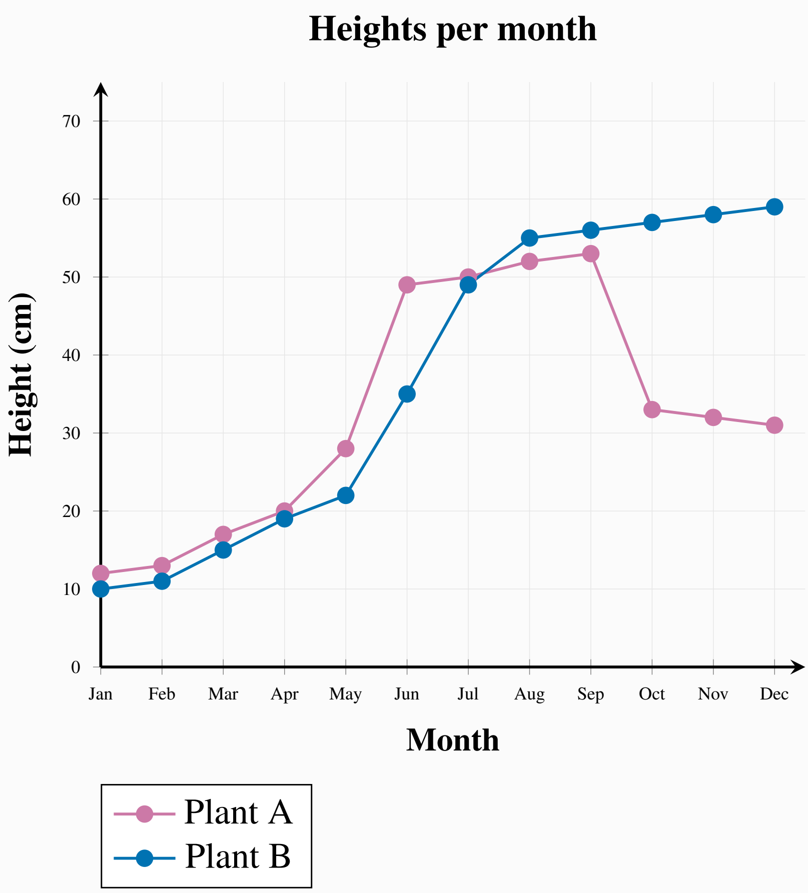
During which month did **Plant B** become taller than Plant A?

Jan ○	Apr ○	Jul ○	Oct ○
Feb ○	May ○	Aug ○	Nov ○
Mar ○	Jun ○	Sep ○	Dec ○

Figure A.40 | Statistics question 13

Difficulty: Level 2	**Subscales:** Statistical Reasoning

The heights of two plants, Plant A and Plant B, were measured at the start of every month. Here is the graph of their growth:



Plant A was damaged during the year. During which month did the damage most likely happen?

Jan ○	Apr ○	Jul ○	Oct ○
Feb ○	May ○	Aug ○	Nov ○
Mar ○	Jun ○	Sep ○	Dec ○

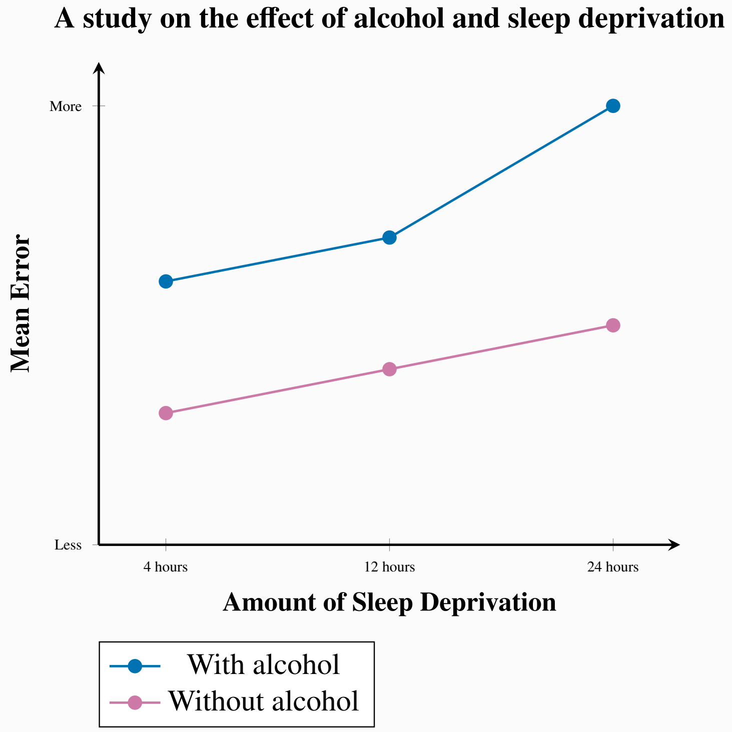
Figure A.41 | Statistics question 14

Difficulty: Level 2	**Subscales:** Statistical Reasoning

Participants were recruited for an experiment and put into two groups. One group was not given any alcohol whilst the other group was instructed to drink 3 units of alcohol prior to starting the experiment.

The graph below shows the ability for each group to complete a task during different stages of sleep deprivation.

The *mean error* measures the average difference from a control group (who have **not** been given alcohol and are **not** sleep deprived) to complete the task.



Which of the following conclusions can be made from this graph?

- No effects of alcohol
- No effects of sleep deprivation
- An interaction effect between alcohol and sleep deprivation
- No effects of alcohol or sleep deprivation

Figure A.42 | Statistics question 15

A.5 Second 30 Personality Items

This subsection shows the second 30 personality items of the BFI-2 that were used in the 2019-2020 study. which follow on from the items asked in Section A.3. Participants were given the same on-screen instructions as the first 30-items.

Table A.2 | The second 30 items of the Big Five Inventory-2 (BFI-2) used to measure personality traits.

The Big Five Inventory-2 (BFI-2) - Second 30 items

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please rate each statement to indicate the extent to which you agree or disagree with that statement.

1=Disagree strongly 2=Disagree a little 3=Neutral; no opinion 4=Agree a little 5=Agree strongly

31. I am someone who is sometimes shy, introverted.
32. I am someone who is helpful and unselfish with others.
33. I am someone who keeps things neat and tidy.
34. I am someone who worries a lot.
35. I am someone who values art and beauty.
36. I am someone who finds it hard to influence people.
37. I am someone who is sometimes rude to others.
38. I am someone who is efficient, gets things done.
39. I am someone who often feels sad.
40. I am someone who is complex, a deep thinker.
41. I am someone who is full of energy.
42. I am someone who is suspicious of others' intentions.
43. I am someone who is reliable, can always be counted on.
44. I am someone who keeps their emotions under control.
45. I am someone who has difficulty imagining things.
46. I am someone who is talkative.
47. I am someone who can be cold and uncaring.
48. I am someone who leaves a mess, doesn't clean up.
49. I am someone who rarely feels anxious or afraid.
50. I am someone who thinks poetry and plays are boring.
51. I am someone who prefers to have others take charge.
52. I am someone who is polite, courteous to others.
53. I am someone who is persistent, works until the task is finished.
54. I am someone who tends to feel depressed, blue.
55. I am someone who has little interest in abstract ideas.
56. I am someone who shows a lot of enthusiasm.
57. I am someone who assumes the best about people.
58. I am someone who sometimes behaves irresponsibly.
59. I am someone who is temperamental, gets emotional easily.
60. I am someone who is original, comes up with new ideas.

A.6 Subjective Numeracy Scale

This subsection shows the Subjective Numeracy Scale (SNS) by Fagerlin et al. (2007) that was used in the 2019-2020 study.

Table A.3 | The 8-item SNS (Fagerlin et al., 2007) used to determine a participant's level of subjective numeracy.

Subjective Numeracy Scale (SNS)

Numerical ability (1 = Not at all good, 6 = Extremely good)

1. How good are you at working with fractions?
2. How good are you at working with percentages?
3. How good are you at calculting a 15% tip?
4. How good are you at figuring out how much a shirt will cost if it is 25% off?

Preference for display of numerical information

5. When reading the newspaper, how helpful do you find tables and graphs that are parts of a story?
   (1 = Not at all, 6 = Extremely)
6. When people tell you the chance of something happening, do you prefer that they use words (e.g., "it rarely happens") or numbers (e.g., "there's a 1% chance")?
   (1 = Always prefer words, 6 = Always prefer numbers)
7. When you hear a weather forecast, do you prefer predictions using percentages (e.g., "there will be a 20% chance of rain today") or predictions using only words (e.g., "there will be a small chance of rain today")?
   (1 = Always prefer percentages, 6 = Always prefer words)
8. How often do you find numerical information to be useful?
   (1 = Never, 6 = Very often)

A.7 Mathematics Anxiety Scale

This subsection shows the items in the Adult Everyday Mathematics Anxiety Scale (AEMAS) (Rolison et al., 2016) that was used in the 2019-2020 study.

Table A.4 | The 13-item AEMAS (Rolison et al., 2016) used to measure mathematics anxiety.

Adult Everyday Mathematics Anxiety Scale (AEMAS)

In the following, you will be presented with some everyday situations. Please rate each item in terms of how anxious you would feel during the event specified.

1=Low anxiety *2=Some anxiety* *3=Moderate anxiety* *4=Quite a bit of anxiety* *5=High anxiety*

1. Having to work with fractions.
2. Having to work with percentages.
3. Having to work out a 15% tip.
4. Figuring how much a shirt will cost if it is 25% off.
5. Having to work out prices in a foreign currency.
6. Looking at tables and graphs when reading a newspaper.
7. Being presented with numerical information about different mobile phone subscription options.
8. Having to choose between financial investment options.
9. Reading your bank's leaflet about changes in terms of using your credit card.
10. Having to complete a maths course as part of your work training.
11. Having to sit a numeracy test as part of a job application.
12. Having to present numerical information at a work meeting.
13. Making an important decision in the workplace based on last year's statistical reports.

B Questions Used in the 2021-2022 Study

Appendix B Contents

This section shows the questions that were used in the 2021-2022 study. There were five compulsory sections in this study and the questions are presented here in the order that they appeared to participants. The numeracy and statistics questions were randomised in an attempt to prevent participants from remembering answers. There were two sets of numeracy and statistics questions that were used in the 2021-2022 study: one set that was given at the pre-test; the other set that was given at the post-test. Each corresponding question is shown side-by-side for comparison in Section B.2 and Section B.3.

B.1 Demographic Questions

This subsection shows the demographic questions that were used in the 2021-2022 study. These questions were designed to determine a participant's age, gender, previous education experience and whether they took a post-16 mathematics qualification. Whilst all questions were shown at the pre-test, only the question shown in Figure B.1 (age question) was shown again at the post-test on the basis that this was the only demographic characteristic deemed to change between the pre-test and the post-test.

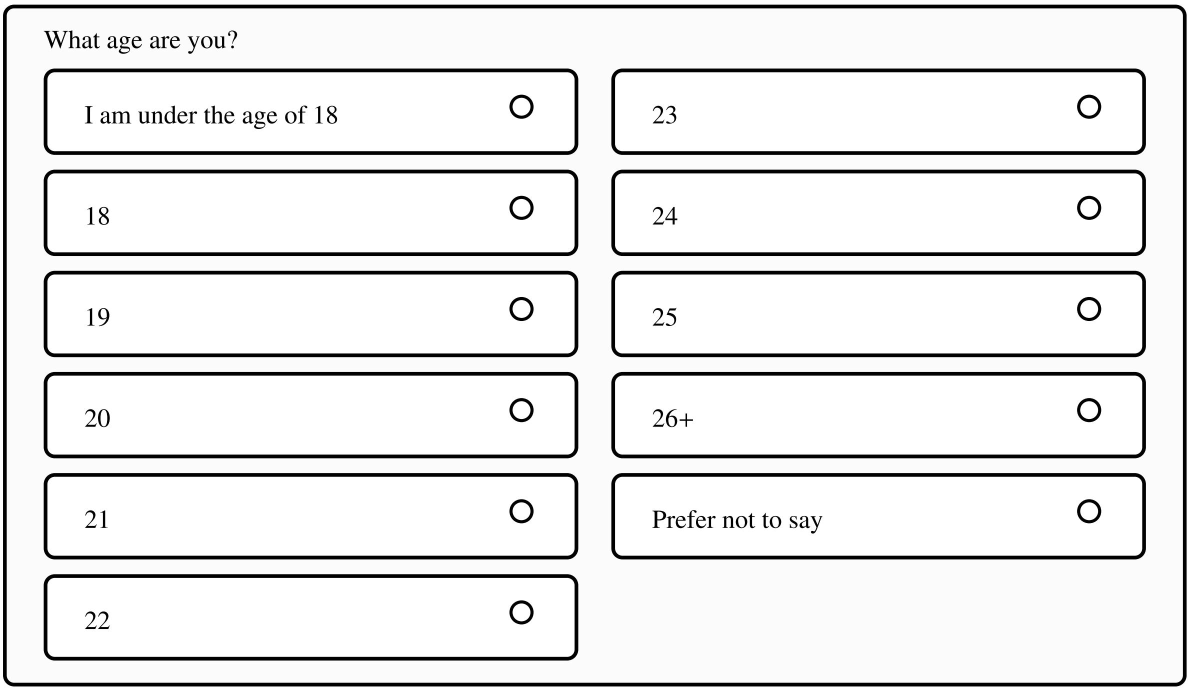
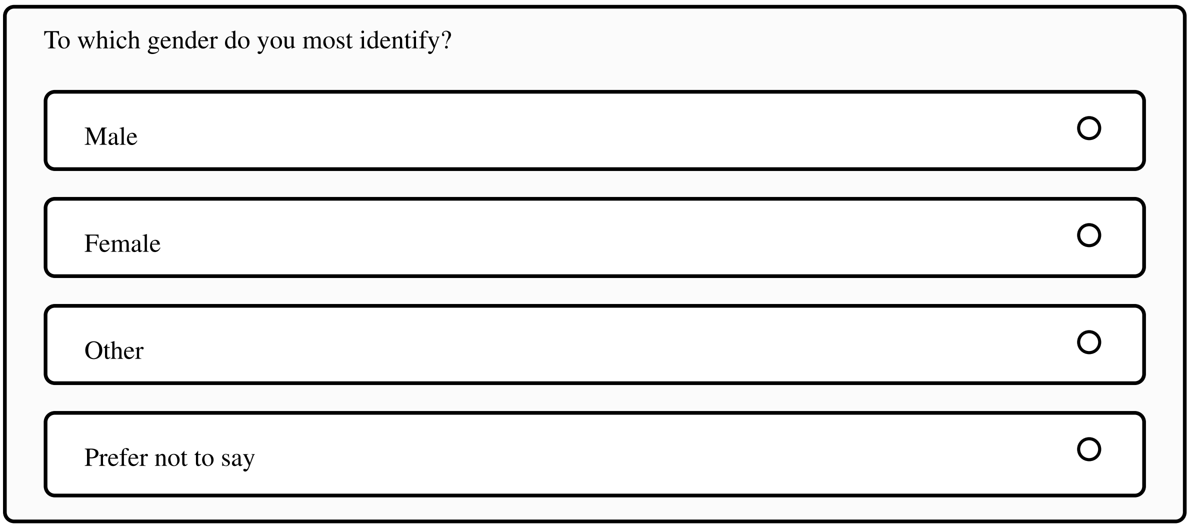


Figure B.1 | First demographic question to determine a participant's age.


To which gender do you most identify?

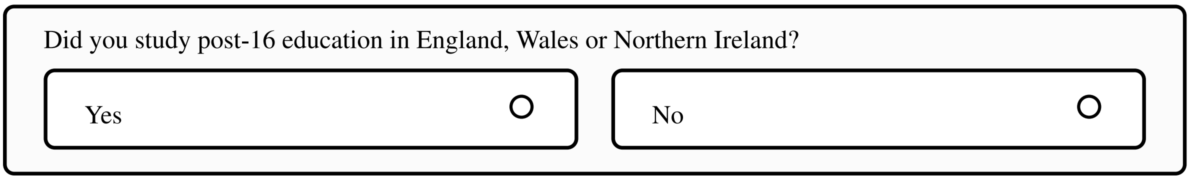
Male

Female

Other

Prefer not to say

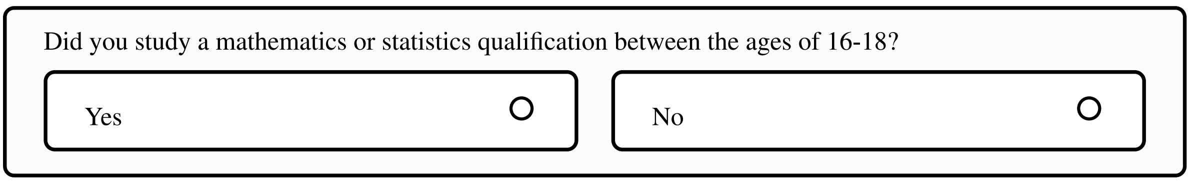
Figure B.2 | Second demographic question to determine a participant's gender.


Did you study post-16 education in England, Wales or Northern Ireland?

Yes

No

Figure B.3 | Third demographic question to determine where a participant studied between the ages of 16-18. Participants who selected *Yes* were classified as *UK participants*, whereas participants who selected *No* were classified as *non-UK participants*. Note that this question does not stipulate Scotland since they use a different education system to the rest of the UK (see Section D.1.3), so for the purposes of this study, participants from Scotland were classified as *non-UK participants*.


Did you study a mathematics or statistics qualification between the ages of 16-18?

Yes

No

Figure B.4 | Fourth demographic question to determine whether a participant studied a mathematics or statistics qualification between the ages of 16-18.

Which of the following mathematics or statistics qualifications have you studied?

Select all that apply.

Level 3 Core Mathematics ○	A-Level Statistics ○
AS-Level Mathematics ○	IB Maths Studies SL ○
A-Level Mathematics ○	IB Mathematics SL ○
AS-Level Further Mathematics ○	IB Mathematics HL ○
A-Level Further Mathematics ○	IB Further Mathematics HL ○
AS-Level Statistics ○	None of the above ○

Figure B.5 | Fifth demographic question to determine which mathematics or statistics qualification a participant studied between the ages of 16-18. This question was only asked to participants who had selected *Yes* to the question in Figure B.3 and *Yes* to the question in Figure B.4 i.e., participants who were from the UK and who had studied a post-16 mathematics or statistics qualification.

Did you study/are you studying a foundation year at university?

Yes ○	No ○

Figure B.6 | Sixth demographic question to determine whether participants studied a foundation year at university.

Please type the name of your degree scheme in the box below.

For example, Psychology.

Figure B.7 | Seventh demographic question to determine the name of a participant's degree course. Since the 2021-2022 study was run online, a unique link was sent to each department so that a participant's department could be determined. However, each department may run multiple degree courses so this seventh demographic question was designed to determine this information.

B.2 Numeracy Questions

This subsection shows the numeracy questions that were used in the 2021-2022 study. Each questions has been numbered here for ease of reference, although this does not correspond to the order in which the questions were shown to participants since the numeracy questions were shown in a randomised order. In addition to the order of the questions being randomised, the multiple-choice options corresponding to each question were also shown in a randomised order. This randomisation was implemented to control for participants from copying each others' solutions in the unlikely event that they worked together. There were two sets of numeracy questions that were given to participants: one set at the pre-test; the other set at the post-test. Each question that was shown at the pre-test and the corresponding question that was shown at the post-test is presented side-by-side here for ease of comparison.

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

Buses for Colchester leave the bus station every 12 minutes.

Buses for Ipswich leave the bus station every 50 minutes.

A bus for Colchester and a bus for Ipswich leave the bus station together at 09:00

Assuming that all buses leave on time, when is the next time that a bus for Colchester and a bus for Ipswich will leave the bus station together?

- 09:50
- 11:00
- 12:00
- 14:00

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A red light flashes every 15 seconds.

A green light flashes every 72 seconds.

The lights flash together at 10:00

When is the next time that the lights will flash together again?

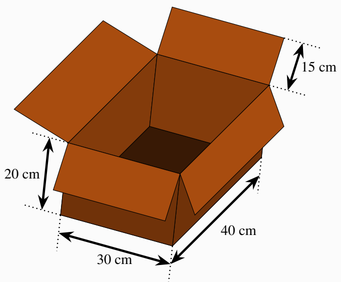
- 10:06
- 10:18
- 10:36
- 11:02

(b) Question shown at the post-test

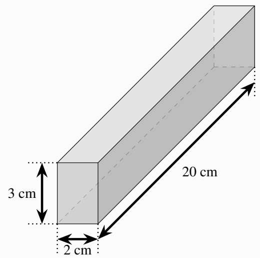
Figure B.8 | Numeracy question 1

Difficulty: Level 1	**Subscales:** Calculation

The diagram below shows a cardboard box that has a width of 30 cm, a length of 40 cm and a height of 20 cm. There are flaps on the top and bottom of the box which each have a width of 15 cm as shown.



Samara is trying to pack the box with as many identical cartons as she can. The diagram below shows that each carton has a width of 2cm, a length of 20 cm and a height of 3 cm.



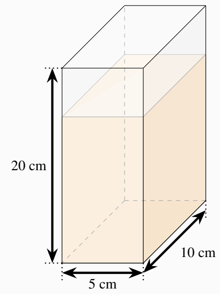
The cartons can be packed in the box in any orientation. What is the maximum number of cartons that will fit in the box?

- 120
- 180
- 195
- 200

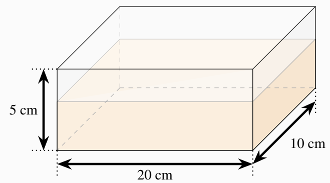
(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Calculation

The diagram below shows a carton of orange juice that has a width of 5 cm, a length of 10 cm and a height of 20 cm. The carton is $\frac{3}{4}$ full of orange juice.



Samara tips the carton on its side as shown in the diagram below.



What is the depth of the orange juice when it lays in this orientation?

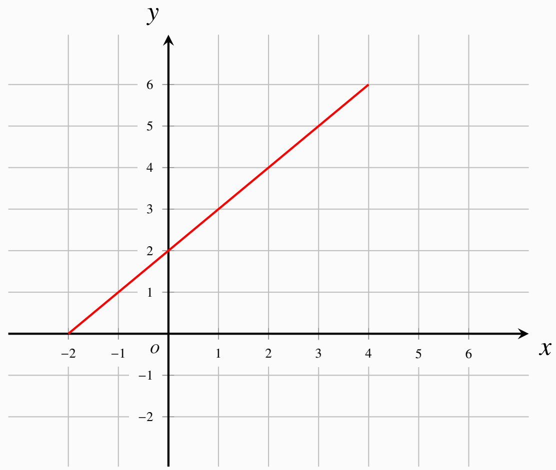
- 0.75 cm
- 3 cm
- 3.75 cm
- 4.25 cm

(b) Question shown at the post-test

Figure B.9 | Numeracy question 2

Difficulty: Level 1	**Subscales:** Algebra

The diagram below shows a graph of y against x



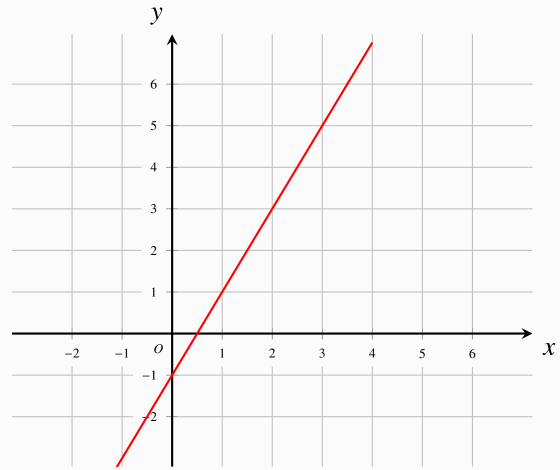
What is the equation of the red line?

- $y = 2x$
- $y = x$
- $y = 2x + 1$
- $y = x + 2$

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Algebra

The diagram below shows a graph of y against x



What is the equation of the red line?

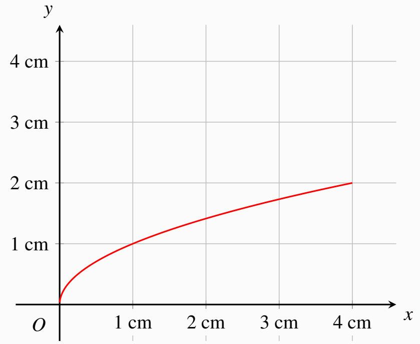
- $y = 2x$
- $y = x - 1$
- $y = 2x - 1$
- $y = -x + 2$

(b) Question shown at the post-test

Figure B.10 | Numeracy question 3

Difficulty: Level 2	**Subscales:** Algebra, Conversions

The diagram below shows a graph of $y = \sqrt{x}$



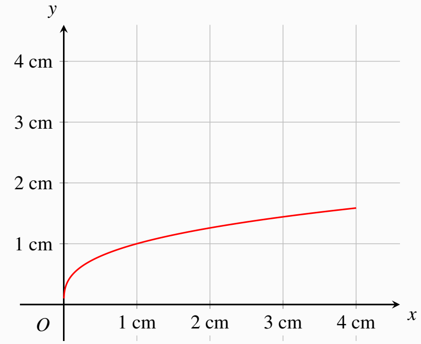
Each unit on the x- and y-axes is worth 1 centimetre. If x represents length and y represents height how long would the graph need to be, in metres, to reach a height of 2 metres?

- 4 metres
- 40 metres
- 400 metres
- 4000 metres

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Algebra, Conversions

The diagram below shows a graph of $y = \sqrt[3]{x}$



Each unit on the x- and y-axes is worth 1 centimetre. If x represents length and y represents height how long would the graph need to be, in metres, to reach a height of 2 metres?

- 8 metres
- 80 metres
- 8000 metres
- 80 000 metres

(b) Question shown at the post-test

Figure B.11 | Numeracy question 4

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

Drax Power Station is the UK's largest power station located in North Yorkshire with a capacity to generate 3.9 GigaWatts of energy to meet the electrical needs of the UK. Due to climate change, the UK government is set to ban all electricity generated from burning coal by 2025. At the start of 2020, one third of energy generated by Drax Power Station was produced by burning coal. The remaining two thirds of energy came from biomass.

An alternative to burning coal is to use onshore wind turbines as they use a renewable energy source. Each onshore wind turbine can produce 2.6 MegaWatts of energy.

Approximately how many onshore wind turbines would be required to replace the amount of energy that Drax Power Station generates from burning coal?

1 MegaWatt = 1 000 000 Watts
1 GigaWatt = 1 000 000 000 Watts

- 2
- 50
- 200
- 500

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

The Ordnance Survey (OS) is the mapping agency for Great Britain. It creates up-to-date maps that show the topography of the UK geography. The first OS map was published in 1801 and today offers over 1000 different paper maps to buy as well as various online versions.

One type of OS map is the Explorer Map. There are 403 OS Explorer Maps available which each cover a different part of the UK. The OS Explorer Maps each use a scale of 1 : 25 000, meaning that every 1 centimetre distance on the map represents 25 000 centimetres in real-life scale. Each OS Explorer Map is printed on paper that is divided into squares that are exactly 4 centimetres apart to make it easier to reference. Each Explorer Map covers a real-life area of 18 miles by 12 miles.

Based on the information above, which of the following pair of dimensions give the size of an OS Explorer Map in centimetres?

100 centimetres = 1 metre
1000 metres = 1 kilometre
10 kilometres ≈ 6 miles

- 120×80 centimetres
- 160×100 centimetres
- 96×80 centimetres
- 30×20 centimetres

(b) Question shown at the post-test

Figure B.12 | Numeracy question 5

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A particular lecture takes place three times a week. This lecture always starts 5-minutes later than planned due to students arriving late.

How much time is lost in this lecture over the duration of a 10-week term?

- 15 minutes
- 50 minutes
- 1 hour 50 minutes
- 2 hours 30 minutes

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A particular lecture takes place four times a week for two terms. This lecture always starts 6-minutes later than planned due to students arriving late.

How much time is lost in this lecture over the duration of two 10-week terms?

- 2 hours 40 minutes
- 4 hours
- 4 hours 80 minutes
- 8 hours

(b) Question shown at the post-test

Figure B.13 | Numeracy question 6

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A charity is collecting 20 pence coins. It manages to collect a total of £26.60

How many 20 pence coins does the charity collect?

- 133
- 150
- 230
- 260

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A charity is collecting 5 pence coins. It manages to collect a total of £18.10

How many 5 pence coins does the charity collect?

- 151
- 231
- 302
- 362

(b) Question shown at the post-test

Figure B.14 | Numeracy question 7

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A particular holiday costs 3 600 Euros. If the exchange rate is 1.2 Euros for every £1, how much does the holiday cost in Pounds Sterling?

- £300
- £432
- £3 000 (correct)
- £4 320

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A particular holiday costs 6 300 US Dollars. If the exchange rate is £1 for every 0.75 US Dollars, how much does the holiday cost in Pounds Sterling?

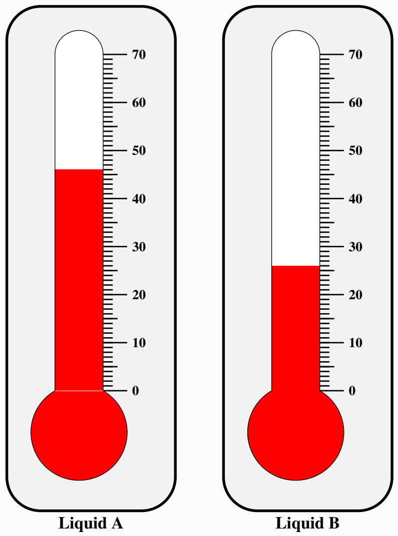
- £15 873
- £1 190
- £4 725
- £8 400 (correct)

(b) Question shown at the post-test

Figure B.15 | Numeracy question 8

Difficulty: Level 1 | **Subscales:** Calculation

The temperatures of Liquid A and Liquid B are measured using two different thermometers. The diagram below shows the temperature readings on the two thermometers.



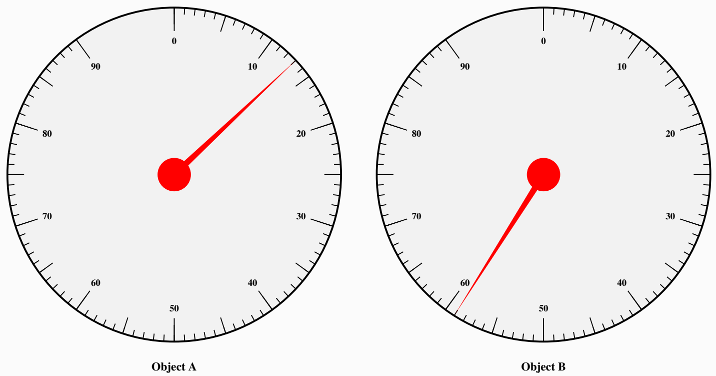
How many degrees hotter is Liquid A than Liquid B?

- 10
- 15
- 20
- 25

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation

The weights of Object A and Object B are measured using different sets of scales. The diagram below shows the weight readings on the dials of the two scales.



How many units heavier is Object B than Object A?

- 36
- 40
- 46
- 50

(b) Question shown at the post-test

Figure B.16 | Numeracy question 9

Difficulty: Level 1 | **Subscales:** Calculation, Algebra

A pencil case consists of 20 coloured pencils. 8 pencils are red, 5 pencils are green and the remaining pencils are blue.

What percentage of the coloured pencils are blue?

- 7%
- 13%
- 27%
- 35%

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Algebra

A jar consists of 25 lollipops. 9 lollipops are red, 12 lollipops are green and the remaining lollipops are blue.

What percentage of the lollipops are blue?

- 4%
- 16%
- 21%
- 36%

(b) Question shown at the post-test

Figure B.17 | Numeracy question 10

Difficulty: Level 2 | **Subscales:** Algebra

a and *b* are two numbers. If *a* and *b* are both doubled, how many times will $(ab)^2$ increase?

- 2 times
- 4 times
- 8 times
- 16 times

(a) Question shown at the pre-test

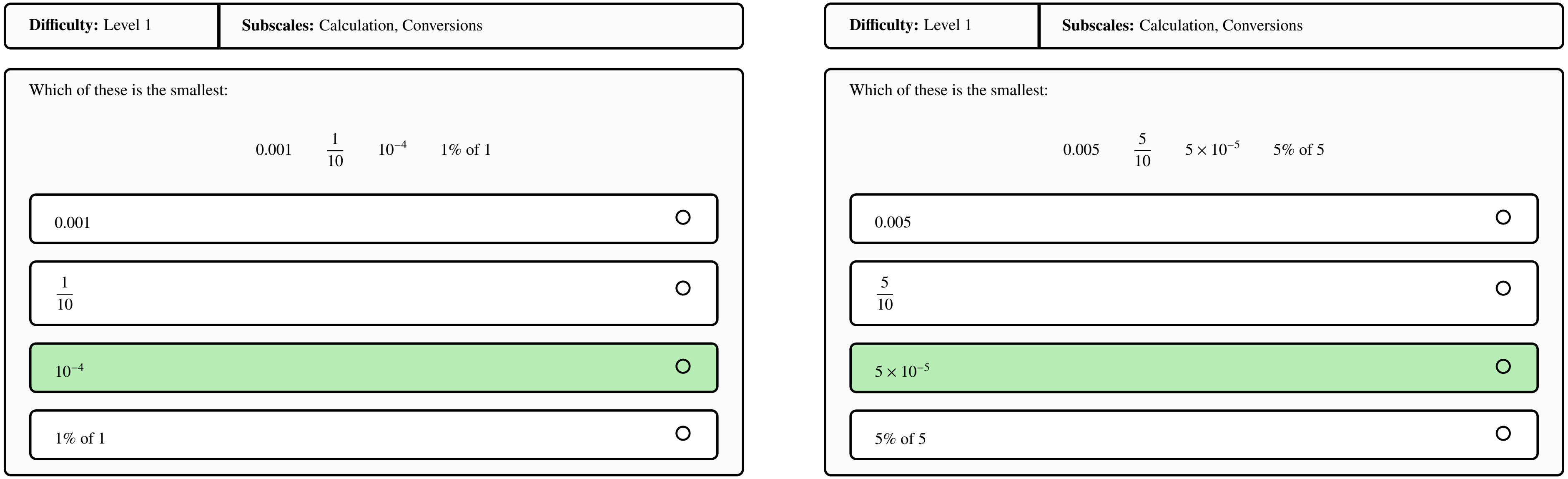
Difficulty: Level 2 | **Subscales:** Algebra

a and *b* are two numbers. If *a* and *b* are both doubled, how many times will $(ab)^3$ increase?

- 2 times
- 8 times
- 32 times
- 64 times

(b) Question shown at the post-test

Figure B.18 | Numeracy question 11



(a) Question shown at the pre-test

(b) Question shown at the post-test

Figure B.19 | Numeracy question 12

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A school canteen is making soup for lunch. It anticipates that it will need to serve 800 bowls of soup. Each bowl contains 400 millilitres of soup. The canteen cooks the soup in large saucepans that can hold up to 50 litres of soup.

What is the minimum number of saucepans which the canteen will need to use in order to serve 800 bowls of soup for lunch?

- 4
- 5
- 6
- 7

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A bakery is making cakes. It anticipates that it will selll 300 cakes that day. Each cake uses exactly 400 grams of cake mixture. The bakery makes the cakes using large bowls that can hold up to 60 kilograms of cake mixture.

What is the minimum number of bowls that the bakery will need to use in order to make 300 cakes?

- 1
- 2
- 3
- 4

(b) Question shown at the post-test

Figure B.20 | Numeracy question 13

Difficulty: Level 2	**Subscales:** Conversions, Estimation

Two cyclists go out for a bike ride together. Cyclist A is from the UK and is used to working in miles, whereas Cyclist B is from France and is used to working in kilometres. At the end of the ride they compare distances. Cyclist B cycled 25 kilometres, whereas because Cyclist A lives a little further away, they cycled a further 12 miles.

What is the total distance that Cyclist A cycled in miles?

10 kilometres ≈ 6 miles

- 24 miles
- 27 miles
- 37 miles
- 52 miles

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Conversions, Estimation

Two hikers go out for a walk together. Hiker A is from the UK and is used to working in miles, whereas Hiker B is from Germany and is used to working in kilometres. At the end of the walk they compare distances. Hiker B walked 6 kilometres, whereas because Hiker A lives a little further away, they walked a further 2 miles.

What is the total distance that Hiker A walked in miles?

10 kilometres ≈ 6 miles

- 3 miles
- 5.6 miles
- 8 miles
- 18 miles

(b) Question shown at the post-test

Figure B.21 | Numeracy question 14

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

An assessment finds that a student has a reading age of 15 years and 3 months. Exactly a year ago the same student had a reading age that was 16 months lower.

What was the student's reading age a year ago?

- 13 years and 7 months
- 13 years and 11 months
- 14 years and 4 months
- 14 years and 7 months

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

An intelligence test finds that an adult has an IQ age of 35 years and 4 months. Exactly a year ago the same adult had an IQ age that was 18 months lower.

What was the adult's IQ age a year ago?

- 33 years and 6 months
- 33 years and 10 months
- 34 years and 6 months
- 34 years and 10 months

(b) Question shown at the post-test

Figure B.22 | Numeracy question 15

B.3 Statistics Questions

This subsection shows the numeracy questions that were used in the 2021-2022 study. In the same manner as the numeracy questions in Section B.2, the questions are numbered here for ease of reference, although this does not correspond to the order in which the questions were shown to participants since the statistics questions were also shown in a randomised order. In addition to the order of the questions being randomised, the multiple-choice options corresponding to each question were also shown in a randomised order. This randomisation was implemented to control for participants from copying each others' solutions in the unlikely event that they worked together. There were two sets of statistics questions that were given to participants: one set at the pre-test; the other set at the post-test. Each question that was shown at the pre-test and the corresponding question that was shown at the post-test is presented side-by-side here for ease of comparison.

Difficulty: Level 2 | **Subscales:** Calculation

60 students sit a test. The students are divided into two groups.

The mean mark of the 20 students in Group A is 30

The mean mark of Group B is 45

What is the mean mark of all 60 students?

- 30
- 37.5
- 40
- 75

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Calculation

50 students sit a test. The students are divided into two groups.

The mean mark of the 40 students in Group A is 20

The mean mark of Group B is 15

What is the mean mark of all 50 students?

- 30
- 15
- 19
- 35

(b) Question shown at the post-test

Figure B.23 | Statistics question 1

Difficulty: Level 2 | **Subscales:** Estimation

The table below shows data about the transactions made by a clothing retailer.

	Type of Transaction			
	Online	**Mail Order**	**Telephone**	**In-Store**
Total number of transactions (in thousands)	40	3	12	60
Average number of items purchased per transaction	13	6	2	9
Percentage of transactions from repeat customers	45%	84%	65%	22%

Approximately how many items were bought in-store?

- 60
- 540
- 60 000
- 540 000

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Estimation

The restaurant allows its customers to order food in one of four ways: order online and get food delivered to their door; order online and collect the food themselves as a takeaway service; eat in the restaurant without a booking; eat in the restaurant as an advance booking.

The table below shows data about the types of orders made on a particularl night in the restaurant.

	Type of Order			
	Delivery	**Takeaway**	**Eat-in (no booking)**	**Eat-in (advance booking)**
Total number of orders	100	75	25	10
Average cost of order	£30	£45	£60	£50
Average gratuity tip given as a percentage of the total cost of order	1%	2%	10%	15%

Approximately how much money was taken in gratuity tips for eat-in orders made with an advance booking?

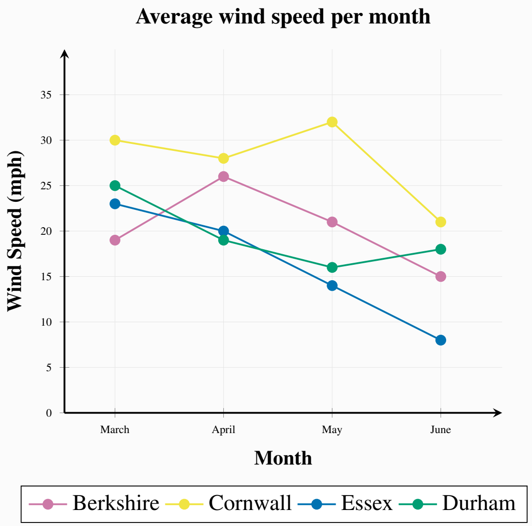
- £1.50
- £7.50
- £75.00
- £7 500.00

(b) Question shown at the post-test

Figure B.24 | Statistics question 2

Difficulty: Level 1	**Subscales:** Estimation

The graph below shows weather data from four UK counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



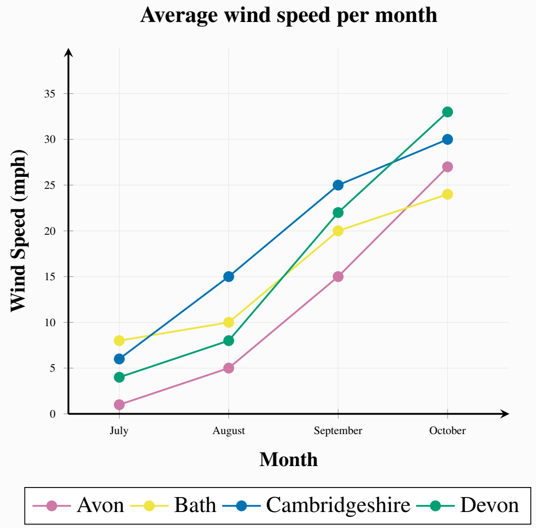
What was the average wind speed between March and June for Cornwall?

- 15 mph
- 23 mph
- 28 mph
- 33 mph

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Estimation

The graph below shows weather data from four UK counties (Avon, Bath, Cambridgeshire and Devon) over a four-month period.



What was the average wind speed between July and October for Cambridgeshire?

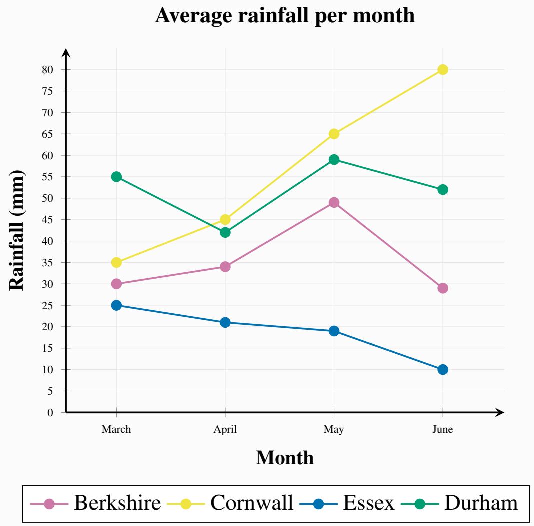
- 11 mph
- 15 mph
- 19 mph
- 23 mph

(b) Question shown at the post-test

Figure B.25 | Statistics question 3

Difficulty: Level 1	**Subscales:** Calculation

The graph below shows weather data from four UK counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



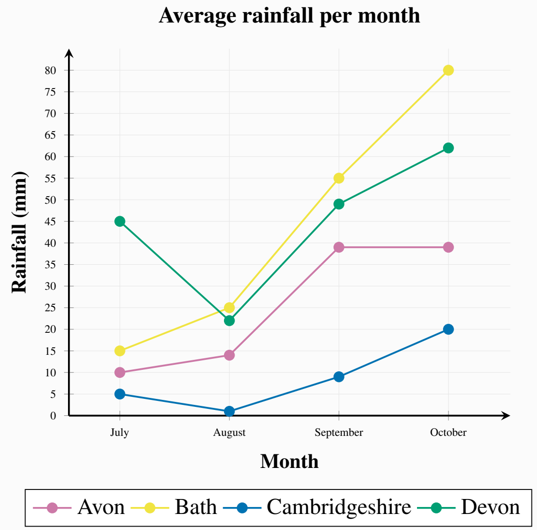
How much more rain did Cornwall get than Essex, on average, during June?

- 10 mm
- 70 mm
- 80 mm
- 90 mm

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Calculation

The graph below shows weather data from four UK counties (Avon, Bath, Cambridgeshire and Devon) over a four-month period.



How much more rain did Bath get than Cambridgeshire, on average, during October?

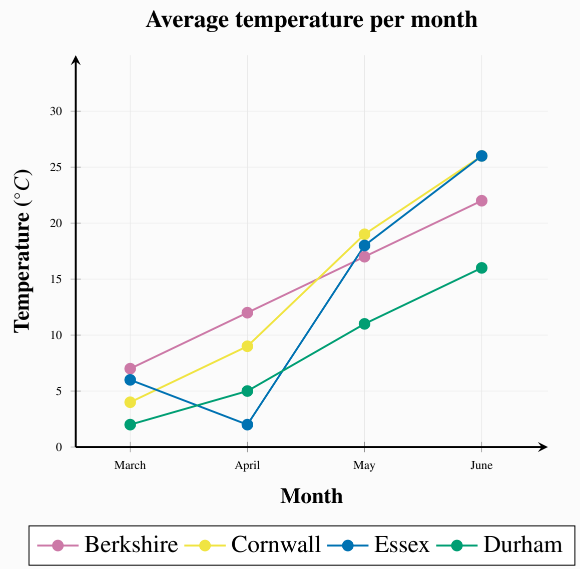
- 30 mm
- 40 mm
- 50 mm
- 60 mm

(b) Question shown at the post-test

Figure B.26 | Statistics question 4

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The graph below shows weather data from four UK counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



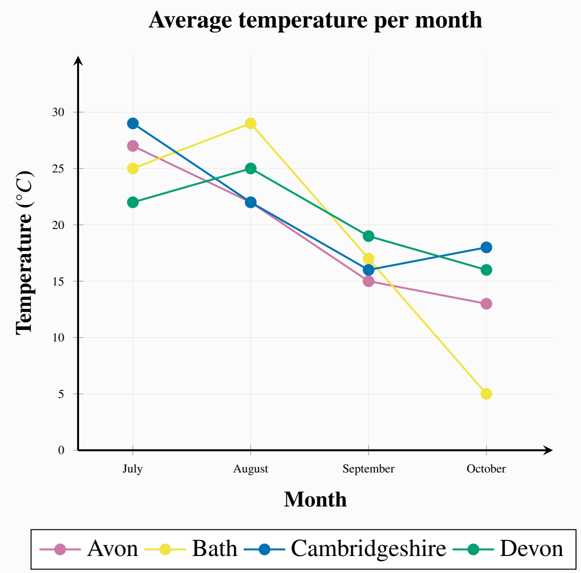
Which county had the biggest range in temperature over the entire four-month period?

- Berkshire
- Cornwall
- Durham
- Essex

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The graph below shows weather data from four UK counties (Avon, Bath, Cambridgeshire and Devon) over a four-month period.



Which county had the biggest range in temperature over the entire four-month period?

- Avon
- Bath
- Cambridgeshire
- Devon

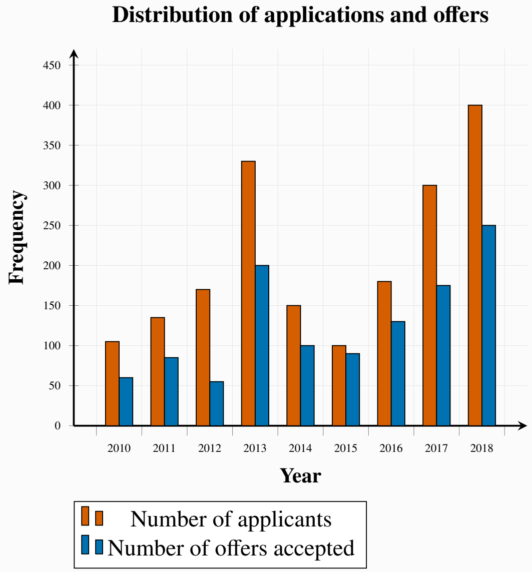
(b) Question shown at the post-test

Figure B.27 | Statistics question 5

Difficulty: Level 1	**Subscales:** Statistical Reasoning

A university department is looking at applicant data for a particular degree scheme.

The graph below shows the number of applicants to the degree scheme and the number of offers which were accepted between the years 2010 and 2018.



Which year had the **highest percentage** of applicants accepting their offers?

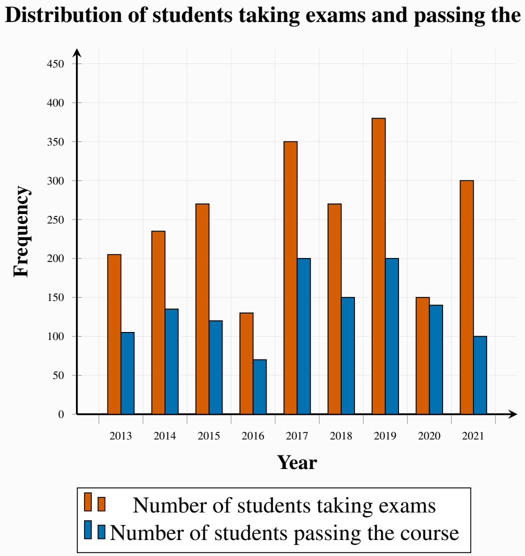
2010 ○	2013 ○	2016 ○
2011 ○	2014 ○	2017 ○
2012 ○	2015 ○	2018 ○

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Statistical Reasoning

A maths department is looking at grade data for their students.

The graph below shows the number of students who took exams and the number of students who passed the course between the years 2013 and 2021.



Which year had the **highest percentage** of students passing the course?

2013 ○	2016 ○	2019 ○
2014 ○	2017 ○	2020 ○
2015 ○	2018 ○	2021 ○

(b) Question shown at the post-test

Figure B.28 | Statistics question 6

Difficulty: Level 2 | **Subscales:** Estimation

30 fish were caught in a pond; each one was tagged and then released.

The next day, 50 fish were caught and 10 were found to have tags on.

Estimate the total number of fish in the pond.

- 70
- 120
- 150
- 200

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Estimation

40 ducks were caught in a park; each one was tagged and then released.

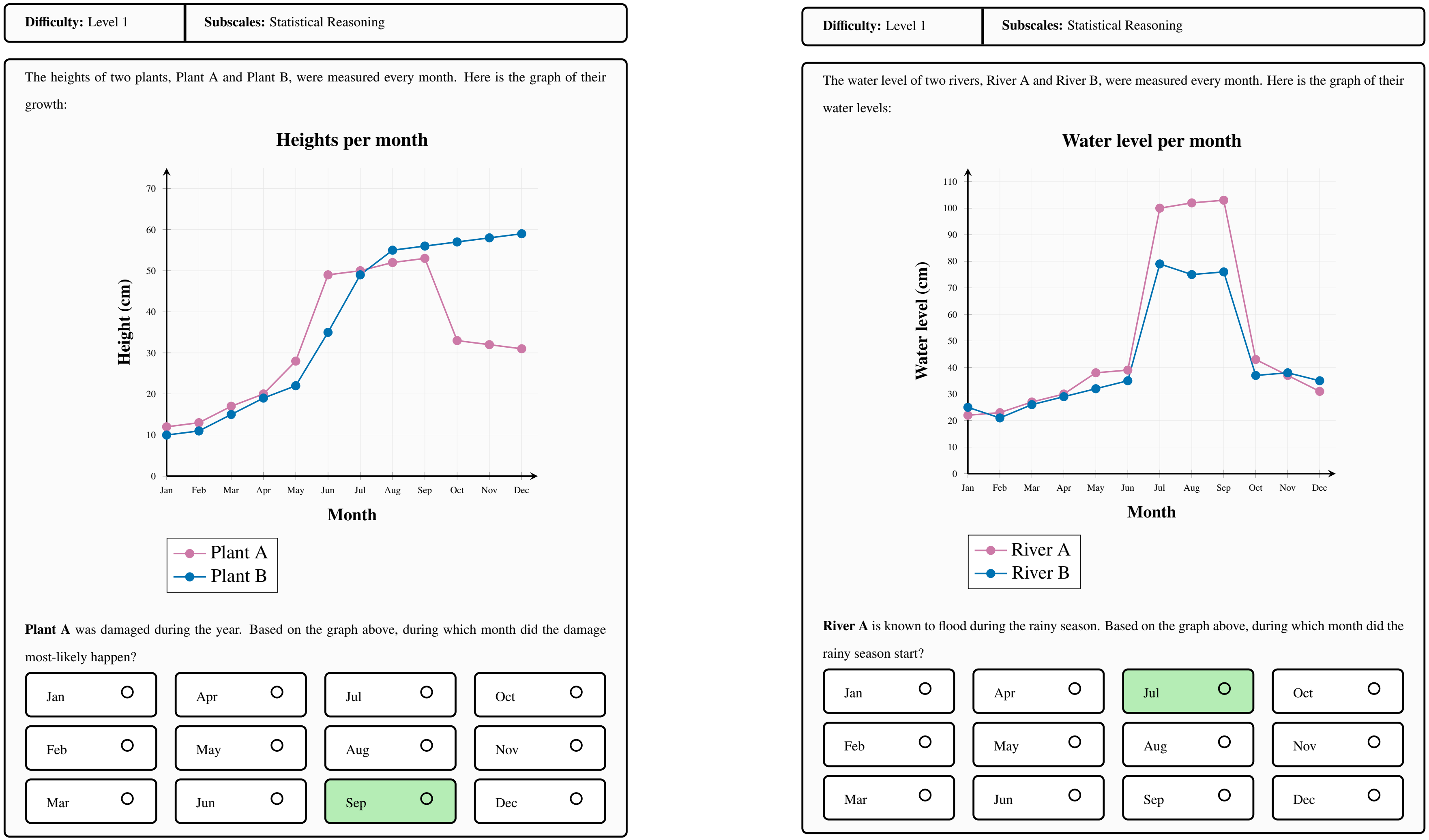
The next day, 60 ducks were caught and 15 were found to have tags on.

Estimate the total number of ducks in the pond.

- 60
- 150
- 160
- 200

(b) Question shown at the post-test

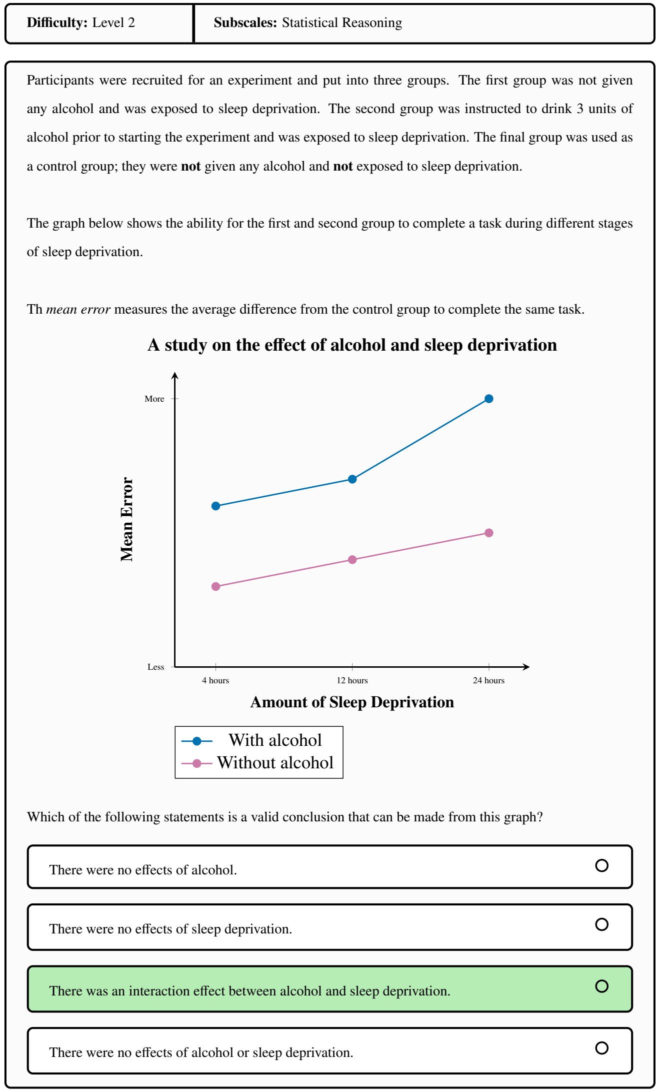
Figure B.29 | Statistics question 7



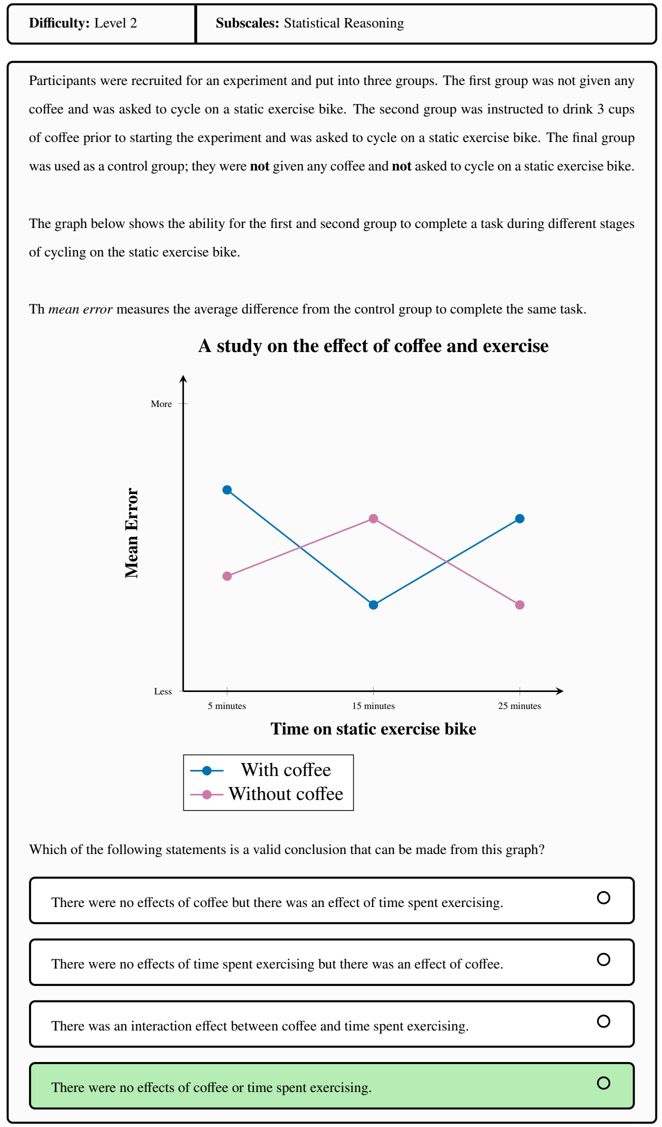
(a) Question shown at the pre-test

(b) Question shown at the post-test

Figure B.30 | Statistics question 8



(a) Question shown at the pre-test



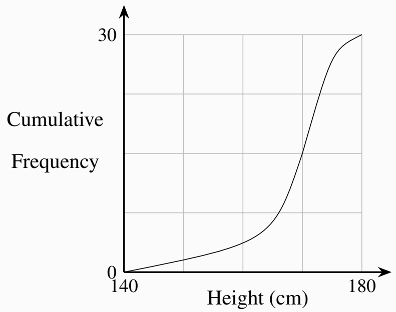
(b) Question shown at the post-test

Figure B.31 | Statistics question 9

Difficulty: Level 2	**Subscales:** Statistical Reasoning

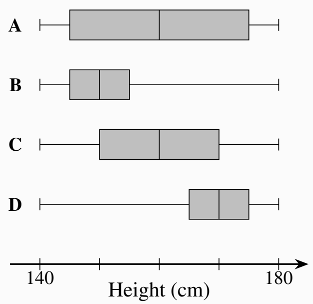
The heights of a group of 30 students are plotted in the following cumulative frequency graph.

Cumulative frequency graph of height



The same data is plotted in a box plot.

Which of the following box plots corresponds with the cumulative frequency graph shown above?



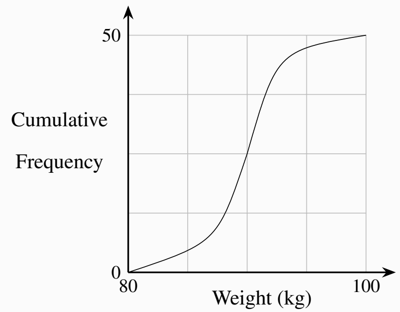
- A
- B
- C
- D

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Statistical Reasoning

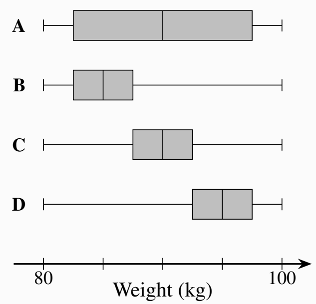
The weights of a group of 50 students are plotted in the following cumulative frequency graph.

Cumulative frequency graph of weight



The same data is plotted in a box plot.

Which of the following box plots corresponds with the cumulative frequency graph shown above?



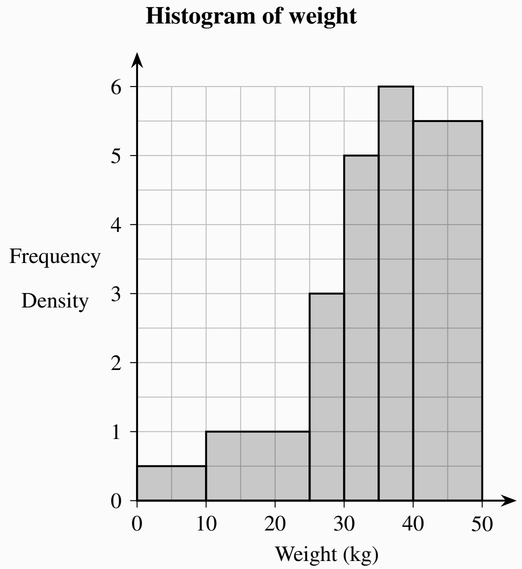
- A
- B
- C
- D

(b) Question shown at the post-test

Figure B.32 | Statistics question 10

Difficulty: Level 2 | **Subscales:** Estimation, Statistical Reasoning

The histogram below shows the weights, in kg, of a group of animals in a zoo.



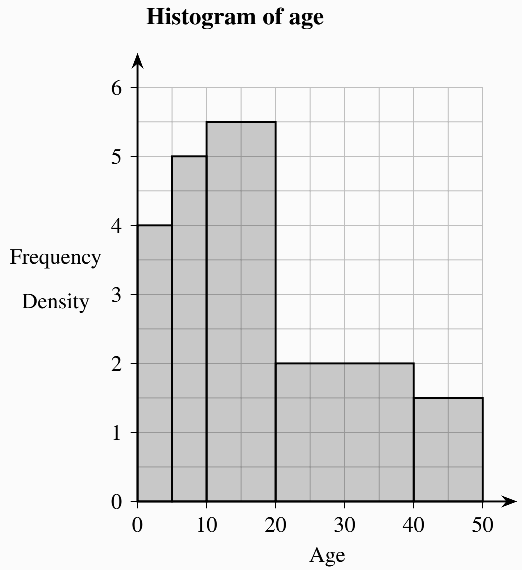
Find an estimate for the median weight of the animals, in kg.

- 5 kg
- 31 kg
- 33 kg
- 38 kg

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Estimation, Statistical Reasoning

The histogram below shows the ages, in years, of a group of people in a school.



Find an estimate for the median age, in years.

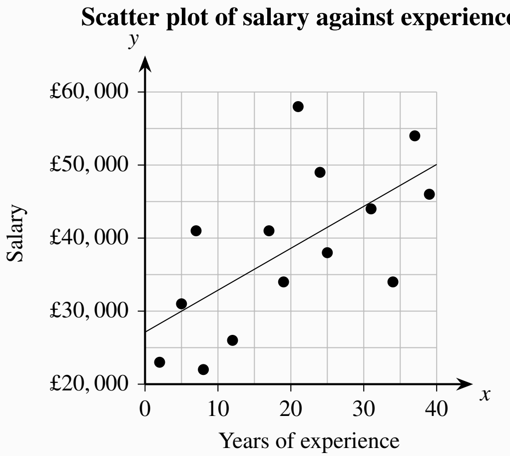
- 10
- 17
- 25
- 30

(b) Question shown at the post-test

Figure B.33 | Statistics question 11

Difficulty: Level 2	**Subscales:** Statistical Reasoning

The scatter plot below shows the relationship between salary (y) and years of experience (x) for employees in a particular company.



The regression line (line of best fit) for the given data is drawn on the scatter plot.

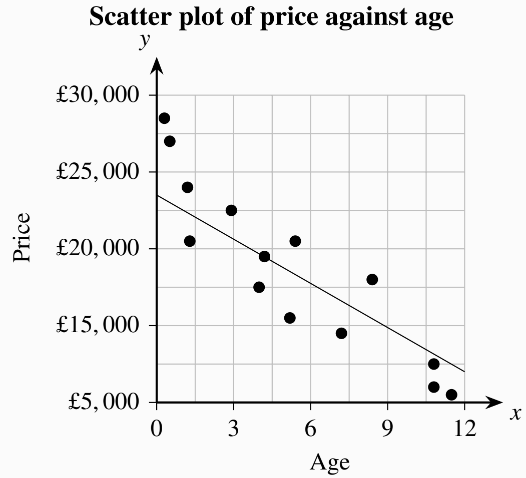
What is the equation of the regression line?

- $y = 574x + 27\,122$
- $y = 27\,122x + 574$
- $y = -574x + 27\,122$
- $y = -27\,122x + 574$

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Statistical Reasoning

The scatter plot below shows the relationship between price (y) and age (x) for different types of cars in a used car showroom.



The regression line (line of best fit) for the given data is drawn on the scatter plot.

What is the equation of the regression line?

- $y = -200x + 27\,000$
- $y = 27\,000x + 200$
- $y = 200x + 27\,000$
- $y = -27\,000x + 200$

(b) Question shown at the post-test

Figure B.34 | Statistics question 12

Difficulty: Level 2	**Subscales:** Statistical Reasoning

A linear model is proposed for the winning 100 m sprint time at the Athletics Championships.

Let y represent the winning runner's time for that year, in seconds.
Let x represent the number of years that have passed since a time was set.

The equation of the regression line (line of best fit) is

$$y = 10.2 - 0.1x$$

Which statement describes what the -0.1 means in the regression equation?

- The fastest recorded time was 0.1 seconds faster than the next fastest time. ○
- The slowest recorded time was 0.1 seconds faster than the next fastest time. ○
- Every year, the runners are approximately 0.1 seconds slower than the last year. ○
- Every year, the runners are approximately 0.1 seconds faster than the last year. ○

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Statistical Reasoning

A linear model is proposed for distance that an electric car is able to travel for a given amount of charge left in its batteries.

Let y represent the distance, in miles.
Let x represent the amount of charge left in the batteries, in percentage of total charge capacity.

The equation of the regression line (line of best fit) is

$$y = 1.5 + 7.2x$$

Which statement describes what the 1.5 means in the regression equation?

- The car uses 1.5% of charge for every mile that it travels. ○
- The car must have a minimum of 1.5% of charge in order to move. ○
- The car is able to travel 1.5 miles of distance if there is no charge left in its batteries. ○
- The car travels 1.5 miles for every percent of charge. ○

(b) Question shown at the post-test

Figure B.35 | Statistics question 13

Difficulty: Level 2	**Subscales:** Calculation

A class of students were asked whether they preferred mathematics or statistics. Each student had to choose exactly one subject. The two-way table below shows which subject was preferred and which gender the student identifies to.

	Mathematics	**Statistics**	**Total**
Male	18	2	**20**
Female	16	13	**29**
Other	1	0	**1**
Total	**35**	**15**	**50**

A student is chosen from the class at random.

Given that the student is male, what is the probability that this student prefers mathematics?

- 36%
- 51%
- 55%
- 90%

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Calculation

A class of students were asked which type of drink they preferred. Each student had to choose exactly one drink. The two-way table shows which drink was preferred and which gender the students identified to.

	Tea	**Coffee**	**Total**
Male	15	4	**19**
Female	18	12	**30**
Other	0	1	**1**
Total	**33**	**17**	**50**

A student is chosen from the class at random.

Given that the student is female, what is the probability that this student prefers coffee?

- 24%
- 40%
- 60%
- 71%

(b) Question shown at the post-test

Figure B.36 | Statistics question 14

Difficulty: Level 2 | **Subscales:** Calculation

A historical artefact is discovered by a team of archaeologists. The archaeologists want to determine how old the artefact is. Three tests are conducted which have varying levels of accuracy.

Test 1: Historical records tell them that the age is 5 400 ± 120 years old.

Test 2: Relative dating tells them that the age is between 5 500 and 6 000 years old.

Test 3: Radiocarbon dating gives the age as 5 600 years old with an error margin of 10%

What is the minimum age of the artefact that is consistent with all three tests?

- 5 040 years old
- 5 280 years old
- 5 400 years old
- 5 500 years old

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Calculation

A new rock formation is discovered by a team of geologists. The geologists want to determine how old the rock formation is. Three tests are conducted which have varying levels of accuracy.

Test 1: Fossils found close to the formation tell them that the age is 6 300 ± 120 million years old.

Test 2: Relative dating tells them that the age is between 5 800 and 6 200 million years old.

Test 3: Radiometric dating gives the age as 6 600 years old with an error margin of 10%

What is the minimum age of the rock formation that is consistent with all three tests?

- 5 800 million years old
- 5 940 million years old
- 6 180 million years old
- 7 260 million years old

(b) Question shown at the post-test

Figure B.37 | Statistics question 15

B.4 Mathematics Anxiety Scale

This subsection shows the items in the Adult Everyday Mathematics Anxiety Scale (AEMAS) (Rolison et al., 2016) that was used in the 2021-2022 study. Each item asked participants to indicate their level of anxiety in the specified event using a 5-point Likert scale (1=Low anxiety; 5=High anxiety).

Table B.1 | The 13-item AEMAS (Rolison et al., 2016) used to measure mathematics anxiety.

Adult Everyday Mathematics Anxiety Scale (AEMAS)

In the following, you will be presented with some everyday situations. Please rate each item in terms of how anxious you would feel during the event specified.

1=Low anxiety *2=Some anxiety* *3=Moderate anxiety* *4=Quite a bit of anxiety* *5=High anxiety*

1. Having to work with fractions.

2. Having to work with percentages.

3. Having to work out a 15% tip.

4. Figuring how much a shirt will cost if it is 25% off.

5. Having to work out prices in a foreign currency.

6. Looking at tables and graphs when reading a newspaper.

7. Being presented with numerical information about different mobile phone subscription options.

8. Having to choose between financial investment options.

9. Reading your bank's leaflet about changes in terms of using your credit card.

10. Having to complete a maths course as part of your work training.

11. Having to sit a numeracy test as part of a job application.

12. Having to present numerical information at a work meeting.

13. Making an important decision in the workplace based on last year's statistical reports.

B.5 COVID-19 Questions

This subsection shows the items that were used in the 2021-2022 study to determine the perceived effect of COVID-19 on a participant's education. Since the study took place in September 2021 and again in January 2022, some of the participants were still studying online, whereas some were studying on campus. The questions established where a participant studied during the COVID-19 outbreak and then proceeded to ask participants to indicate their level of agreement with the given statement using a 5-point Likert scale (1=Strongly disagree; 5=Strongly agree).

B.5.1 Questions Shown at the pre-test

Were you in education during the COVID-19 (Coronavirus) outbreak anytime between March 2020 and August 2021?

- Yes ○
- No ○

Figure B.38 | The first COVID-19 question to establish whether a participant was in education during the Coronavirus pandemic.

Where did the majority of your lessons take place between March 2020 and August 2021?

- I had mostly face-to-face lessons that took place in a classroom. ○
- I had mostly online lessons ○
- I had an even split between online lessons and face-to-face lessons in a classroom. ○
- I did not have any lessons. ○

Figure B.39 | The second COVID-19 question to establish where a participant studied during the Coronavirus pandemic.

Table B.2 | The 5-item COVID-19 instrument used to establish the perceived impact of the Coronavirus on a participant's education that was asked at the pre-test.

COVID-19 Questionnaire at the pre-test

In the following, you will be presented with some statements about the impact of COVID-19 on your education. Please rate your agreement with each of the given statements.

1=Stongly disagree 2=Somewhat disagree 3=Neither agree nor disagree 4=Somewhat agree 5=Strongly agree

1. COVID-19 had no impact on my education.
2. COVID-19 limited my access to learning resources (e.g., books, teachers, websites).
3. COVID-19 made me change the methods that I usually use to learn and study.
4. I think that I generally achieved higher grades than I would have if I had sat physical exams in the exam period of 2020 and 2021.
5. COVID-19 has meant that I do not know as much content as I would have liked at the start of my degree course.

B.5.2 Questions Shown at the post-test

Where did the majority of your lectures and contact hours take place in the autumn term (between October 2021 and December 2021)?

- I had mostly face-to-face lectures and contact hours that took place on campus. ○
- I had mostly online lectures and contact hors that took place remotely. ○

Figure B.40 | The first COVID-19 question asked at the post-test to establish whether a participant studied online or face-to-face during the first term of university.

Table B.3 | The 2-item COVID-19 instrument used to establish the perceived impact of the Coronavirus on a participant's education that was asked at the post-test.

COVID-19 Questionnaire at the post-test

In the following, you will be presented with some statements about the impact of COVID-19 on your education. Please rate your agreement with each of the given statements.

1=Stongly disagree 2=Somewhat disagree 3=Neither agree nor disagree 4=Somewhat agree 5=Strongly agree

1. COVID-19 has restricted my access to resources and facilities (these may include campus learning facilities such as the library and quiet working areas, or it may include resources such as textbooks or lecture notes).
2. The transition to university was made harder because of COVID-19.

C Questions Used in the 2022-2023 Study

Appendix C Contents

C.1 Demographic Questions

This subsection shows the demographic questions which were used in the 2022-2023 study.

What age are you?

18 ○	23 ○
19 ○	24 ○
20 ○	25 ○
21 ○	Other (please type): ☐ ○
22 ○	Prefer not to say ○

Figure C.1 | First demographic question to determine a participant's age.

To which gender do you most identify?

- Male ○
- Female ○
- Other ○
- Prefer not to say ○

Figure C.2 | Second demographic question to determine a participant's gender.

Did you study post-16 education in England, Wales or Northern Ireland?

Yes ○	No ○

Figure C.3 | Third demographic question to determine a participant's gender.

Did you study a mathematics or statistics qualification between the ages of 16-18?

- Yes ○
- No ○

Figure C.4 | Fourth demographic question to determine a participant's gender.

Which of the following mathematics or statistics qualifications have you studied?

Select all that apply.

- Level 3 Core Mathematics ○
- A-Level Statistics ○
- AS-Level Mathematics ○
- IB Maths Studies SL ○
- A-Level Mathematics ○
- IB Mathematics SL ○
- AS-Level Further Mathematics ○
- IB Mathematics HL ○
- A-Level Further Mathematics ○
- IB Further Mathematics HL ○
- AS-Level Statistics ○
- None of the above ○

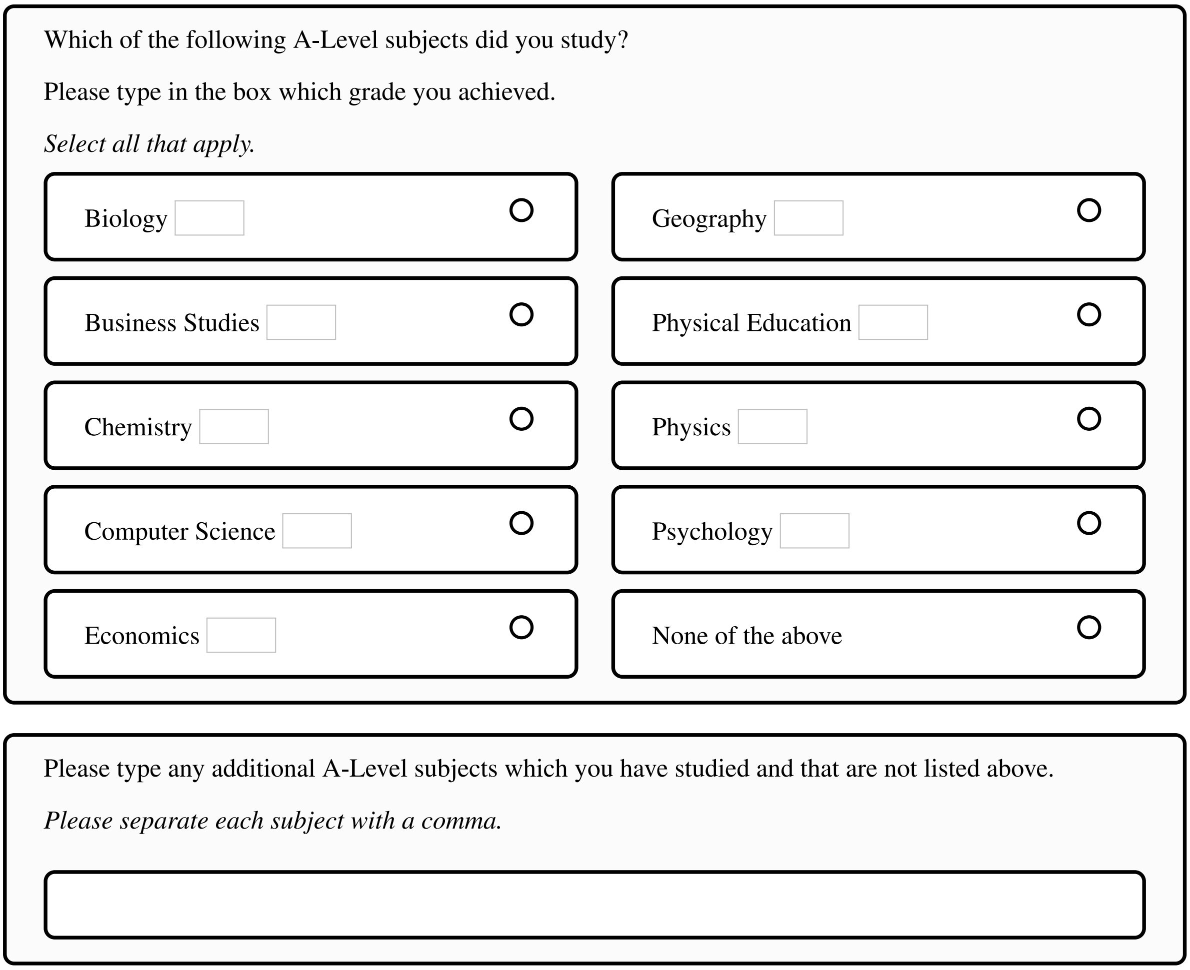
Figure C.5 | Fifth demographic question to determine a participant's gender.

Which of the following qualifications did you study between the ages of 16-18?

Select all that apply.

- A-Levels ○
- International Baccalaureate ○
- BTEC ○
- Other (please type): ______ ○

Figure C.6 | Sixth demographic question to determine a participant's gender.


Which of the following A-Level subjects did you study?

Please type in the box which grade you achieved.

Select all that apply.

Biology	Geography
Business Studies	Physical Education
Chemistry	Physics
Computer Science	Psychology
Economics	None of the above

Please type any additional A-Level subjects which you have studied and that are not listed above.

Please separate each subject with a comma.

Figure C.7 | Seventh demographic question to determine a participant's quantitative A-Level subjects and their grade.

Which of the following IB subjects did you study?

Please type in the box which grade you achieved.

Select all that apply.

Biology ☐ ○	Geography ☐ ○
Business Studies ☐ ○	Physical Education ☐ ○
Chemistry ☐ ○	Physics ☐ ○
Computer Science ☐ ○	Psychology ☐ ○
Economics ☐ ○	None of the above ○

Please type any additional IB subjects which you have studied and that are not listed above.

Please separate each subject with a comma.

Figure C.8 | Eighth demographic question to determine a participant's quantitative IB subjects and their grade.

Please type **all** the subjects which you have studied between the ages of 16-18.

Please separate each subject with a comma.

Figure C.9 | Ninth demographic question to determine a participant's post-16 subjects.

Did you study/are you studying a foundation year at university?

Yes ○	No ○

Figure C.10 | Tenth demographic question to determine whether participants studied a foundation year at university.

Which department at the University of Essex are you from?

- Department of Economics ○
- Department of Government ○
- Department of History ○
- Department of Language and Linguistics ○
- Department of Literature, Film and Theatre Studies ○
- Department of Mathematical Sciences ○
- Department of Psychology ○
- Department of Psychosocial and Psychoanalytic Studies ○
- Department of Sociology ○
- East 15 Acting School ○
- Edge Hotel School ○
- Essex Business School ○
- Essex Law School ○
- Essex Pathways Department ○
- School of Computer Science and Electronic Engineering ○
- School of Health and Social Care ○
- School of Life Sciences ○
- School of Sport, Rehabilitation and Exercise Sciences ○
- UK Data Archive ○
- University of Essex International College ○
- Other (please type): ________ ○

Figure C.11 | Eleventh demographic question to determine whether participants studied a foundation year at university.

Please type the name of your degree scheme in the box below.

For example, Psychology.

Figure C.12 | Twelfth demographic question to determine the name of a participant's degree course. Since the 2022-2023 study was a hybrid study consisting of online and lab-based participants, this question was shown to all participants.

C.2 Numeracy Questions

This subsection shows the numeracy questions which were used in the 2022-2023 study.

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

Buses for Colchester leave the bus station every 12 minutes.

Buses for Ipswich leave the bus station every 50 minutes.

A bus for Colchester and a bus for Ipswich leave the bus station together at 09:00

Assuming that all buses leave on time, when is the next time that a bus for Colchester and a bus for Ipswich will leave the bus station together?

- 09:50
- 11:00
- 12:00
- 14:00

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

A red light flashes every 15 seconds.

A green light flashes every 72 seconds.

The lights flash together at 10:00

When is the next time that the lights will flash together again?

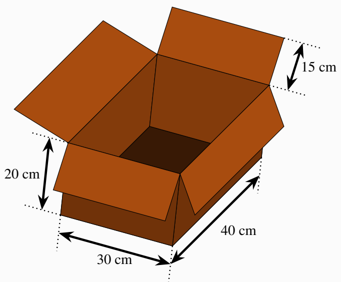
- 10:06
- 10:18
- 10:36
- 11:02

(b) Question shown at the post-test

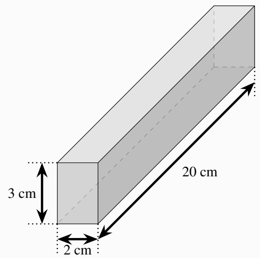
Figure C.13 | Numeracy question 1

Difficulty: Level 1	**Subscales:** Calculation

The diagram below shows a cardboard box that has a width of 30 cm, a length of 40 cm and a height of 20 cm. There are flaps on the top and bottom of the box which each have a width of 15 cm as shown.



Samara is trying to pack the box with as many identical cartons as she can. The diagram below shows that each carton has a width of 2cm, a length of 20 cm and a height of 3 cm.



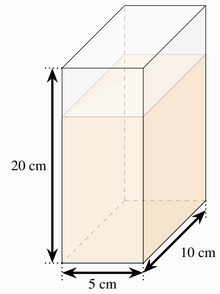
The cartons can be packed in the box in any orientation. What is the maximum number of cartons that will fit in the box?

- 120
- 180
- 195
- 200

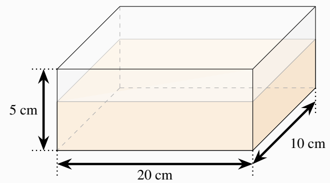
(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Calculation

The diagram below shows a carton of orange juice that has a width of 5 cm, a length of 10 cm and a height of 20 cm. The carton is $\frac{3}{4}$ full of orange juice.



Samara tips the carton on its side as shown in the diagram below.



What is the depth of the orange juice when it lays in this orientation?

- 0.75 cm
- 3 cm
- 3.75 cm
- 4.25 cm

(b) Question shown at the post-test

Figure C.14 | Numeracy question 2

(a) Question shown at the pre-test

(b) Question shown at the post-test

Figure C.15 | Numeracy question 3

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

Drax Power Station is the UK's largest power station located in North Yorkshire with a capacity to generate 3.9 GigaWatts of energy to meet the electrical needs of the UK. Due to climate change, the UK government is set to ban all electricity generated from burning coal by 2025. At the start of 2020, one third of energy generated by Drax Power Station was produced by burning coal. The remaining two thirds of energy came from biomass.

An alternative to burning coal is to use onshore wind turbines as they use a renewable energy source. Each onshore wind turbine can produce 2.6 MegaWatts of energy.

Approximately how many onshore wind turbines would be required to replace the amount of energy that Drax Power Station generates from burning coal?

1 MegaWatt = 1 000 000 Watts

1 GigaWatt = 1 000 000 000 Watts

- 2
- 50
- 200
- 500

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

The Ordnance Survey (OS) is the mapping agency for Great Britain. It creates up-to-date maps that show the topography of the UK geography. The first OS map was published in 1801 and today offers over 1000 different paper maps to buy as well as various online versions.

One type of OS map is the Explorer Map. There are 403 OS Explorer Maps available which each cover a different part of the UK. The OS Explorer Maps each use a scale of 1 : 25 000, meaning that every 1 centimetre distance on the map represents 25 000 centimetres in real-life scale. Each OS Explorer Map is printed on paper that is divided into squares that are exactly 4 centimetres apart to make it easier to reference. Each Explorer Map covers a real-life area of 18 miles by 12 miles.

Based on the information above, which of the following pair of dimensions give the size of an OS Explorer Map in centimetres?

100 centimetres = 1 metre

1000 metres = 1 kilometre

10 kilometres ≈ 6 miles

- 120 × 80 centimetres
- 160 × 100 centimetres
- 96 × 80 centimetres
- 30 × 20 centimetres

(b) Question shown at the post-test

Figure C.16 | Numeracy question 5

Difficulty: Level 2 | **Subscales:** Algebra

a and *b* are two numbers. If *a* and *b* are both doubled, how many times will $(ab)^2$ increase?

- 2 times
- 4 times
- 8 times
- 16 times

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Algebra

a and *b* are two numbers. If *a* and *b* are both doubled, how many times will $(ab)^3$ increase?

- 2 times
- 8 times
- 32 times
- 64 times

(b) Question shown at the post-test

Figure C.17 | Numeracy question 11

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

Which of these is the smallest:

0.001 $\frac{1}{10}$ 10^{-4} 1% of 1

- 0.001
- $\frac{1}{10}$
- 10^{-4}
- 1% of 1

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Calculation, Conversions

Which of these is the smallest:

0.005 $\frac{5}{10}$ 5×10^{-5} 5% of 5

- 0.005
- $\frac{5}{10}$
- 5×10^{-5}
- 5% of 5

(b) Question shown at the post-test

Figure C.18 | Numeracy question 12

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A school canteen is making soup for lunch. It anticipates that it will need to serve 800 bowls of soup. Each bowl contains 400 millilitres of soup. The canteen cooks the soup in large saucepans that can hold up to 50 litres of soup.

What is the minimum number of saucepans which the canteen will need to use in order to serve 800 bowls of soup for lunch?

- 4
- 5
- 6
- 7

(a) Question shown at the pre-test

Difficulty: Level 2	**Subscales:** Conversions, Estimation

A bakery is making cakes. It anticipates that it will selll 300 cakes that day. Each cake uses exactly 400 grams of cake mixture. The bakery makes the cakes using large bowls that can hold up to 60 kilograms of cake mixture.

What is the minimum number of bowls that the bakery will need to use in order to make 300 cakes?

- 1
- 2
- 3
- 4

(b) Question shown at the post-test

Figure C.19 | Numeracy question 13

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

Two cyclists go out for a bike ride together. Cyclist A is from the UK and is used to working in miles, whereas Cyclist B is from France and is used to working in kilometres. At the end of the ride they compare distances. Cyclist B cycled 25 kilometres, whereas because Cyclist A lives a little further away, they cycled a further 12 miles.

What is the total distance that Cyclist A cycled in miles?

10 kilometres ≈ 6 miles

- 24 miles
- 27 miles
- 37 miles
- 52 miles

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Conversions, Estimation

Two hikers go out for a walk together. Hiker A is from the UK and is used to working in miles, whereas Hiker B is from Germany and is used to working in kilometres. At the end of the walk they compare distances. Hiker B walked 6 kilometres, whereas because Hiker A lives a little further away, they walked a further 2 miles.

What is the total distance that Hiker A walked in miles?

10 kilometres ≈ 6 miles

- 3 miles
- 5.6 miles
- 8 miles
- 18 miles

(b) Question shown at the post-test

Figure C.20 | Numeracy question 14

C.3 Statistics Questions

This subsection shows the numeracy questions which were used in the 2022-2023 study.

Difficulty: Level 2 | **Subscales:** Calculation

60 students sit a test. The students are divided into two groups.

The mean mark of the 20 students in Group A is 30

The mean mark of Group B is 45

What is the mean mark of all 60 students?

- 30
- 37.5
- 40
- 75

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Calculation

50 students sit a test. The students are divided into two groups.

The mean mark of the 40 students in Group A is 20

The mean mark of Group B is 15

What is the mean mark of all 50 students?

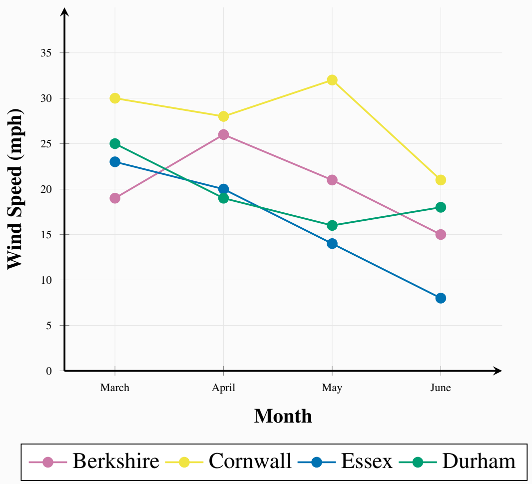
- 30
- 15
- 19
- 35

(b) Question shown at the post-test

Figure C.21 | Statistics question 1

Difficulty: Level 1 | **Subscales:** Estimation

The graph below shows weather data from four UK counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



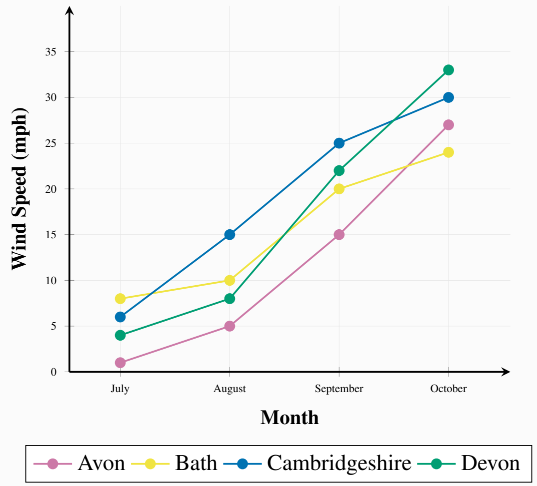
What was the average wind speed between March and June for Cornwall?

- 15 mph
- 23 mph
- 28 mph
- 33 mph

(a) Question shown at the pre-test

Difficulty: Level 1 | **Subscales:** Estimation

The graph below shows weather data from four UK counties (Avon, Bath, Cambridgeshire and Devon) over a four-month period.



What was the average wind speed between July and October for Cambridgeshire?

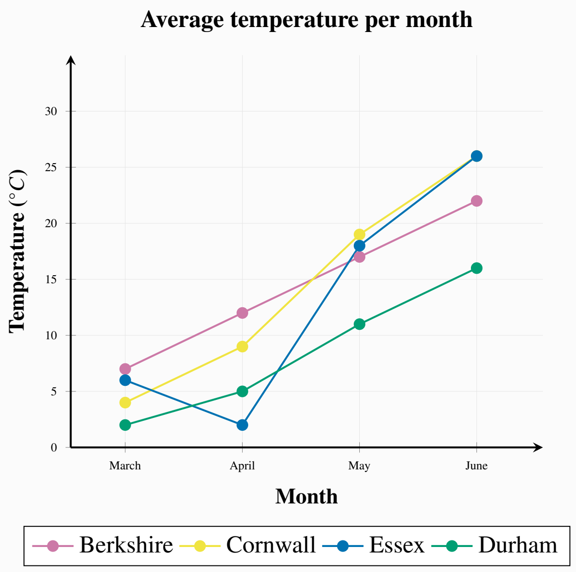
- 11 mph
- 15 mph
- 19 mph
- 23 mph

(b) Question shown at the post-test

Figure C.22 | Statistics question 3

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The graph below shows weather data from four UK counties (Berkshire, Cornwall, Durham and Essex) over a four-month period.



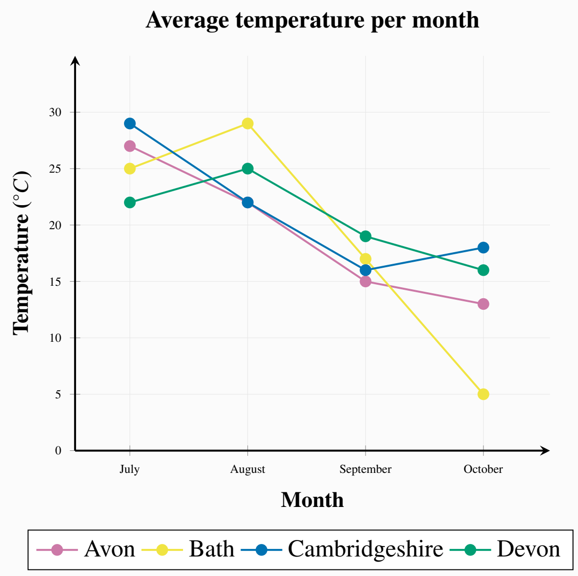
Which county had the biggest range in temperature over the entire four-month period?

- Berkshire ○
- Cornwall ○
- Durham ○
- Essex ○

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The graph below shows weather data from four UK counties (Avon, Bath, Cambridgeshire and Devon) over a four-month period.



Which county had the biggest range in temperature over the entire four-month period?

- Avon ○
- Bath ○
- Cambridgeshire ○
- Devon ○

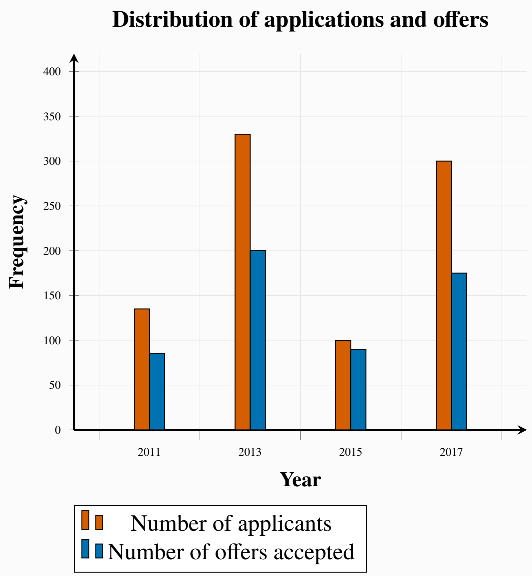
(b) Question shown at the post-test

Figure C.23 | Statistics question 5

Difficulty: Level 1	**Subscales:** Statistical Reasoning

A university department is looking at applicant data for a particular degree scheme.

The graph below shows the number of applicants to the degree scheme and the number of offers which were accepted for the years 2011, 2013, 2015 and 2017.



Which year had the **highest percentage** of applicants accepting their offers?

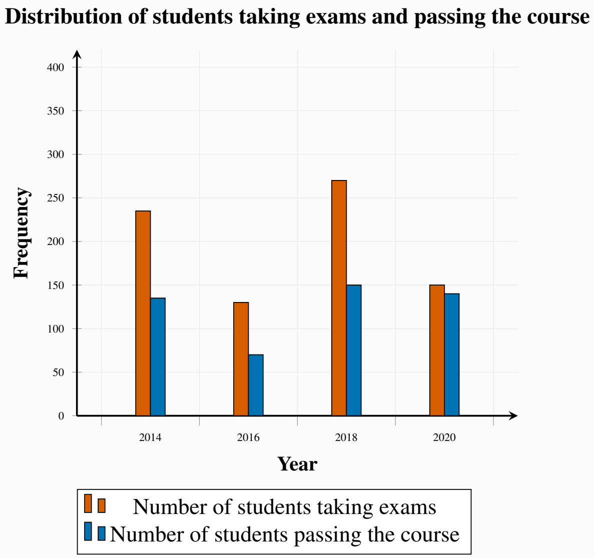
- 2011
- 2013
- 2015
- 2017

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Statistical Reasoning

A maths department is looking at grade data for their students.

The graph below shows the number of students who took exams and the number of students who passed the course for the years 2014, 2016, 2018 and 2020.



Which year had the **highest percentage** of students passing the course?

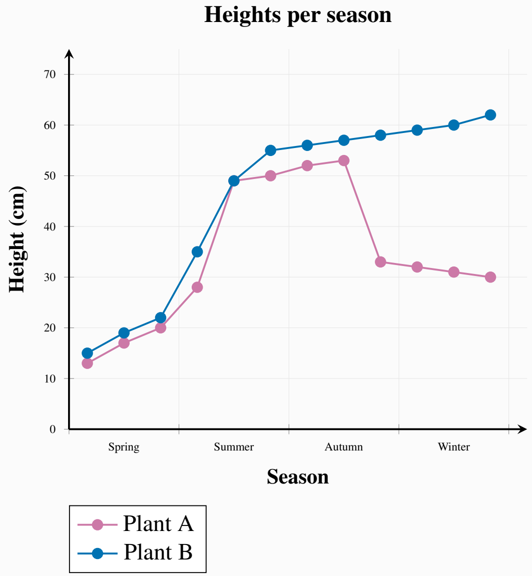
- 2014
- 2016
- 2018
- 2020

(b) Question shown at the post-test

Figure C.24 | Statistics question 6

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The heights of two plants, Plant A and Plant B, were measured every season. Here is the graph of their growth:



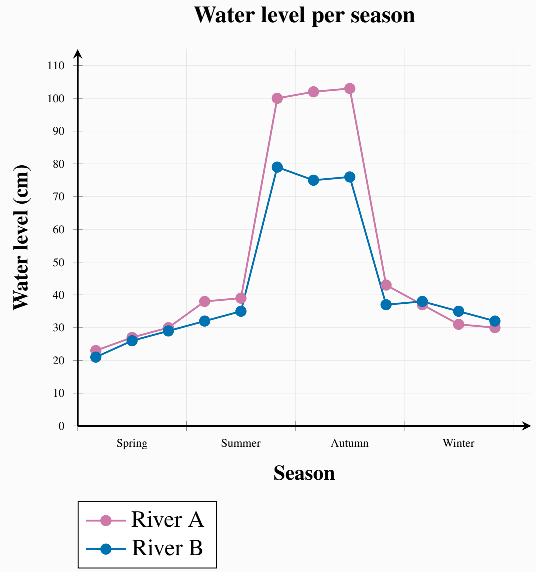
Plant A was damaged during the year. Based on the graph above, during which season did the damage most-likely happen?

- Spring
- Summer
- Autumn
- Winter

(a) Question shown at the pre-test

Difficulty: Level 1	**Subscales:** Statistical Reasoning

The water level of two rivers, River A and River B, were measured every season. Here is the graph of their water levels:



River A is known to flood during the year. Based on the graph above, during which season did the flooding start?

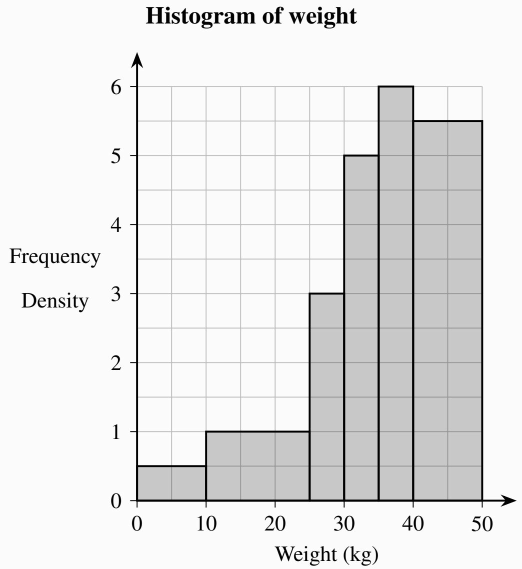
- Spring
- Summer
- Autumn
- Winter

(b) Question shown at the post-test

Figure C.25 | Statistics question 8

Difficulty: Level 2 | **Subscales:** Estimation, Statistical Reasoning

The histogram below shows the weights, in kg, of a group of animals in a zoo.



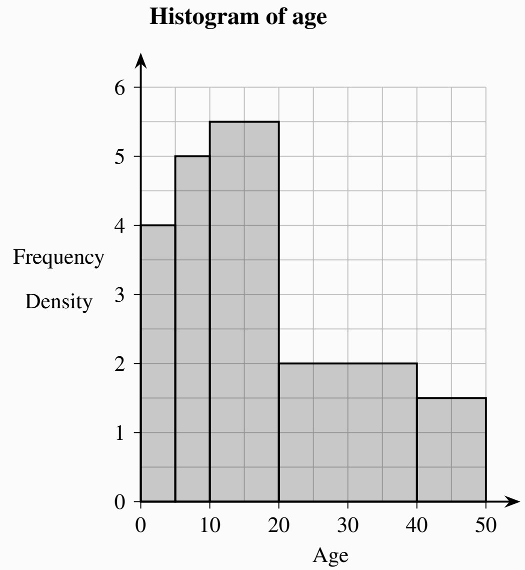
Find an estimate for the median weight of the animals, in kg.

- 5 kg
- 31 kg
- 33 kg
- 38 kg

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Estimation, Statistical Reasoning

The histogram below shows the ages, in years, of a group of people in a school.



Find an estimate for the median age, in years.

- 10
- 17
- 25
- 30

(b) Question shown at the post-test

Figure C.26 | Statistics question 11

Difficulty: Level 2 | **Subscales:** Statistical Reasoning

A linear model is proposed for the winning 100 m sprint time at the Athletics Championships.

Let y represent the winning runner's time for that year, in seconds.

Let x represent the number of years that have passed since a time was set.

The equation of the regression line (line of best fit) is

$$y = 10.2 - 0.1x$$

Which statement describes what the -0.1 means in the regression equation?

- The fastest recorded time was 0.1 seconds faster than the next fastest time.
- The slowest recorded time was 0.1 seconds faster than the next fastest time.
- Every year, the runners are approximately 0.1 seconds slower than the last year.
- Every year, the runners are approximately 0.1 seconds faster than the last year.

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Statistical Reasoning

A linear model is proposed for distance that an electric car is able to travel for a given amount of charge left in its batteries.

Let y represent the distance, in miles.

Let x represent the amount of charge left in the batteries, in percentage of total charge capacity.

The equation of the regression line (line of best fit) is

$$y = 1.5 + 7.2x$$

Which statement describes what the 1.5 means in the regression equation?

- The car uses 1.5% of charge for every mile that it travels.
- The car must have a minimum of 1.5% of charge in order to move.
- The car is able to travel 1.5 miles of distance if there is no charge left in its batteries.
- The car travels 1.5 miles for every percent of charge.

(b) Question shown at the post-test

Figure C.27 | Statistics question 13

Difficulty: Level 2 | **Subscales:** Calculation

A class of students were asked whether they preferred mathematics or statistics. Each student had to choose exactly one subject. The two-way table below shows which subject was preferred and which gender the student identifies to.

	Mathematics	Statistics	Total
Male	18	2	**20**
Female	16	13	**29**
Other	1	0	**1**
Total	**35**	**15**	**50**

A student is chosen from the class at random.

Given that the student is male, what is the probability that this student prefers mathematics?

- 36%
- 51%
- 55%
- 90%

(a) Question shown at the pre-test

Difficulty: Level 2 | **Subscales:** Calculation

A class of students were asked which type of drink they preferred. Each student had to choose exactly one drink. The two-way table shows which drink was preferred and which gender the students identified to.

	Tea	Coffee	Total
Male	15	4	**19**
Female	18	12	**30**
Other	0	1	**1**
Total	**33**	**17**	**50**

A student is chosen from the class at random.

Given that the student is female, what is the probability that this student prefers coffee?

- 24%
- 40%
- 60%
- 71%

(b) Question shown at the post-test

Figure C.28 | Statistics question 14

C.4 Subjective Numeracy Scale

Table C.1 | The 8-item SNS (Fagerlin et al., 2007) used to determine a participant's level of subjective numeracy.

Subjective Numeracy Scale (SNS)

Numerical ability (1 = Not at all good, 6 = Extremely good)

1. How good are you at working with fractions?
2. How good are you at working with percentages?
3. How good are you at calculting a 15% tip?
4. How good are you at figuring out how much a shirt will cost if it is 25% off?

Preference for display of numerical information

5. When reading the newspaper, how helpful do you find tables and graphs that are parts of a story?
   (1 = Not at all, 6 = Extremely)
6. When people tell you the chance of something happening, do you prefer that they use words (e.g., "it rarely happens") or numbers (e.g., "there's a 1% chance")?
   (1 = Always prefer words, 6 = Always prefer numbers)
7. When you hear a weather forecast, do you prefer predictions using percentages (e.g., "there will be a 20% chance of rain today") or predictions using only words (e.g., "there will be a small chance of rain today")?
   (1 = Always prefer percentages, 6 = Always prefer words)
8. How often do you find numerical information to be useful?
   (1 = Never, 6 = Very often)

C.5 Mathematics Anxiety Scale

Table C.2 | The 13-item AEMAS (Rolison et al., 2016) used to measure mathematics anxiety.

Adult Everyday Mathematics Anxiety Scale (AEMAS)

In the following, you will be presented with some everyday situations. Please rate each item in terms of how anxious you would feel during the even specified.

1=Low anxiety *2=Some anxiety* *3=Moderate anxiety* *4=Quite a bit of anxiety* *5=High anxiety*

1. Having to work with fractions.
2. Having to work with percentages.
3. Having to work out a 15% tip.
4. Figuring how much a shirt will cost if it is 25% off.
5. Having to work out prices in a foreign currency.
6. Looking at tables and graphs when reading a newspaper.
7. Being presented with numerical information about different mobile phone subscription options.
8. Having to choose between financial investment options.
9. Reading your bank's leaflet about changes in terms of using your credit card.
10. Having to complete a maths course as part of your work training.
11. Having to sit a numeracy test as part of a job application.
12. Having to present numerical information at a work meeting.
13. Making an important decision in the workplace based on last year's statistical reports.

C.6 Mathematics Attitudes Scale

Table C.3 | The 19 items of the Short Attitudes Towards Mathematics Inventory (Short ATMI) (Lim & Chapman, 2013).

Short Attitudes Towards Mathematics Inventory (Short ATMI)

1=Disagree strongly *2=Disagree a little* *3=Neutral; no opinion* *4=Agree a little* *5=Agree strongly*

Enjoyment

1. I have usually enjoyed studying mathematics in school.
2. I like to solve new problems in mathematics.
3. I really like mathematics.
4. I am happier in a mathematics class than in any other class.
5. Mathematics is a very interesting subject.

Motivation

6. I am confident that I could learn advanced mathematics.
7. I am willing to take more than the required amount of mathematics.
8. I plan to take as much mathematics as I can during my education.
9. The challenge of mathematics appeals to me.

Sense of Security

10. Studying mathematics makes me feel nervous.
11. I am always under a terrible strain in a mathematics class.
12. It makes me nervous to even think about having to do a mathematics problem.
13. I am always confused in my mathematics class.
14. I feel a sense of insecurity when attempting mathematics.

Value

15. Mathematics is a very worthwhile and necessary subject.
16. Mathematics is important in everyday life.
17. Mathematics is one of the most important subjects for people to study.
18. The mathematics content that I learn at university would be very helpful no matter what I decide to study in the future.
19. A strong mathematics background could help me in my professional life.

Note that Item 18 originally read "College mathematics lessons would be very helpful no matter what I decide to study in the future", however this was adapted to make it suitable for the demographics of participants in this study.

C.7 Personality Instrument

This subsection shows the Big Five Inventory-2 Short (BFI-2-S) as developed by Soto & John (2017a).

Table C.4 | The 30 items of the Big Five Inventory-2 Short (BFI-2-S) used to measure personality traits.

The Big Five Inventory-2-Short (BFI-2-S)

Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please rate each statement to indicate the extent to which you agree or disagree with that statement.

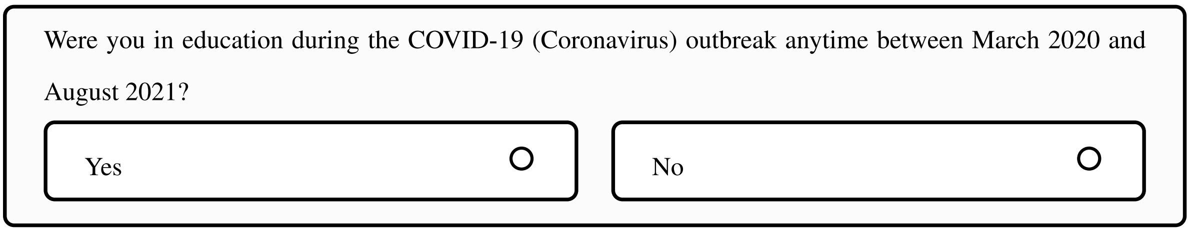
1=Disagree strongly 2=Disagree a little 3=Neutral; no opinion 4=Agree a little 5=Agree strongly

1. I am someone who tends to be quiet.
2. I am someone who is compassionate, has a soft heart.
3. I am someone who tends to be disorganised.
4. I am someone who worries a lot.
5. I am someone who is fascinated by art, music, or literature.
6. I am someone who is dominant, acts as a leader.
7. I am someone who is sometimes rude to others.
8. I am someone who has difficulty getting started on tasks.
9. I am someone who tends to feel depressed, blue.
10. I am someone who has little interest in abstract ideas.
11. I am someone who is full of energy.
12. I am someone who assumes the best about people.
13. I am someone who is reliable, can always be counted on.
14. I am someone who is emotionally stable, not easily upset.
15. I am someone who is original, comes up with new ideas.
16. I am someone who is outgoing, sociable.
17. I am someone who can be cold and uncaring.
18. I am someone who keeps things neat and tidy.
19. I am someone who is relaxed, handles stress well.
20. I am someone who has few artistic interests.
21. I am someone who prefers to have others take charge.
22. I am someone who is respectful, treats others with respect.
23. I am someone who is persistent, works until the task is finished.
24. I am someone who feels secure, comfortable with self.
25. I am someone who is complex, a deep thinker.
26. I am someone who is less active than other people.
27. I am someone who tends to find fault with others.
28. I am someone who can be somewhat careless.
29. I am someone who is temperamental, gets emotional easily.
30. I am someone who has little creativity.

C.8 COVID-19 Questions

This subsection shows the COVID-19 questions which we asked to participants.

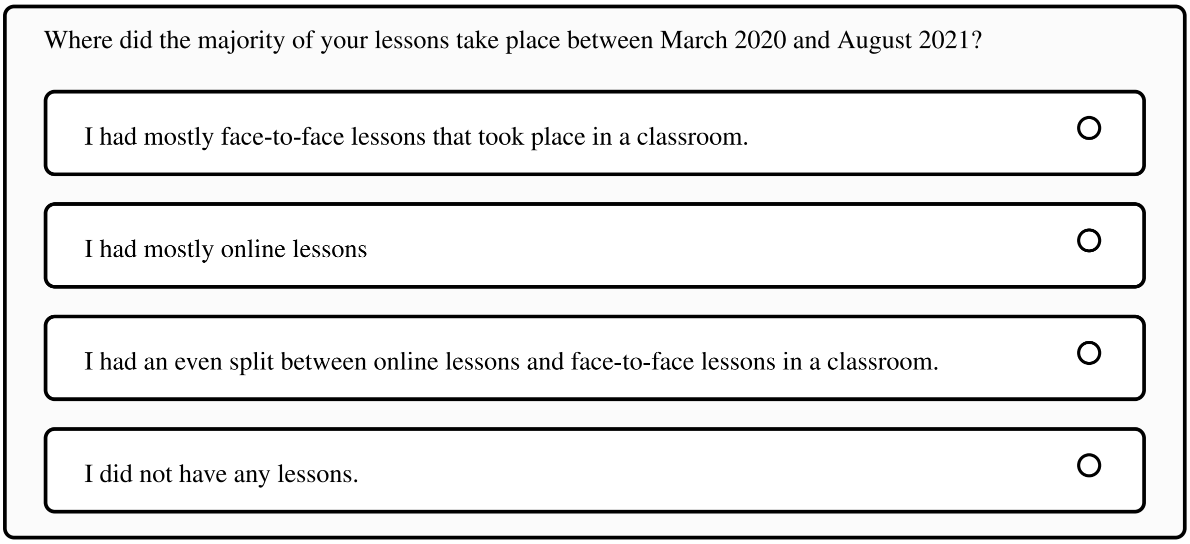
C.8.1 Questions Shown at the pre-test


Were you in education during the COVID-19 (Coronavirus) outbreak anytime between March 2020 and August 2021?

Yes

No

Figure C.29 | The first COVID-19 question to establish whether a participant was in education during the Coronavirus pandemic.


Where did the majority of your lessons take place between March 2020 and August 2021?

I had mostly face-to-face lessons that took place in a classroom.

I had mostly online lessons

I had an even split between online lessons and face-to-face lessons in a classroom.

I did not have any lessons.

Figure C.30 | The second COVID-19 question to establish where a participant studied during the Coronavirus pandemic.

Table C.5 | The 5-item COVID-19 instrument used to establish the perceived impact of the Coronavirus on a participant's education that was asked at the pre-test.

COVID-19 Questionnaire at the pre-test

In the following, you will be presented with some statements about the impact of COVID-19 on your education. Please rate your agreement with each of the given statements.

1=Stongly disagree 2=Somewhat disagree 3=Neither agree nor disagree 4=Somewhat agree 5=Strongly agree

1. COVID-19 had no impact on my education.
2. COVID-19 limited my access to learning resources (e.g., books, teachers, websites).
3. COVID-19 made me change the methods that I usually use to learn and study.
4. I think that I generally achieved higher grades than I would have if I had sat physical exams in the exam period of 2020 and 2021.
5. COVID-19 has meant that I do not know as much content as I would have liked at the start of my degree course.

C.8.2 Questions Shown at the post-test

Where did the majority of your lectures and contact hours take place in the autumn term (between October 2021 and December 2021)?

- I had mostly face-to-face lectures and contact hours that took place on campus. ○
- I had mostly online lectures and contact hors that took place remotely. ○

Figure C.31 | The first COVID-19 question asked at the post-test to establish whether a participant studied online or face-to-face during the first term of university.

Table C.6 | The 2-item COVID-19 instrument used to establish the perceived impact of the Coronavirus on a participant's education that was asked at the post-test.

COVID-19 Questionnaire at the post-test

In the following, you will be presented with some statements about the impact of COVID-19 on your education. Please rate your agreement with each of the given statements.

1=Stongly disagree 2=Somewhat disagree 3=Neither agree nor disagree 4=Somewhat agree 5=Strongly agree

1. COVID-19 has restricted my access to resources and facilities (these may include campus learning facilities such as the library and quiet working areas, or it may include resources such as textbooks or lecture notes).

2. The transition to university was made harder because of COVID-19.

D Post-16 Mathematics

Appendix D Contents

D.1 Curricula of England, Wales, Northern Ireland and Scotland

D.1.1 National Curriculum in England

The National Curriculum was introduced in 1988 and has undergone various changes since its introduction (see Chapter 3 for details of the major education reforms). The most recent reform to the National Curriculum took place under Michael Gove, the then Secretary of State for Education, in 2014 which majorly came into effect in 2017. At the time of writing this thesis, it is the current education framework that is used in England which sets out the education standards that every student between the ages of 5-16 in formal education in England is expected to follow. The National Curriculum is divided into four key stages of learning with the first two key stages applying to Primary Education for students aged 5-11. The next two key stages apply to Secondary Education for students aged 11-16. At the age of 16, the National Curriculum culminates in General Certificate of Secondary Education (GCSE) examinations where every student is expected to achieve a pass standard in a minimum of Mathematics, English and Science, although students will typically take 10 subjects for GCSE.

In England, it is compulsory for all students to remain either in education or employment training until the age of 18, with students who choose to continue in education after the age of 16 enrolling in Further Education. A popular set of qualifications for students in Further Education and of particular interest in this thesis are the Advanced Subsidiary Level (AS-Level) and subsequently the Advanced Level (A-Level). These are examples of *post-16* qualifications or *Level 3* qualifications. Other post-16 education qualifications are available such as the International Baccalaureate (IB), Business and Technology Education Council (BTEC) and Technical Levels (T-Levels) as well as the option to start work under an apprenticeship or traineeship scheme.

Table D.1 | An overview of the key stages of the National Curriculum framework used in England.

School Age	School Year	Stage	Description
4	Reception	Early Years	Primary Education
5	Year 1	Key Stage 1	Primary Education
6	Year 2	Key Stage 1	Primary Education
7	Year 3	Key Stage 2	Primary Education
8	Year 4	Key Stage 2	Primary Education
9	Year 5	Key Stage 2	Primary Education
10	Year 6	Key Stage 2	Primary Education
11	Year 7	Key Stage 3	Secondary Education
12	Year 8	Key Stage 3	Secondary Education
13	Year 9	Key Stage 3	Secondary Education
14	Year 10	Key Stage 4	Secondary Education
15	Year 11	Key Stage 4	Secondary Education - GCSEs
16	Year 12	Key Stage 5	Further Education - AS-Levels
17	Year 13	Key Stage 5	Further Education - A-Levels

Note: School age specifies the age of the student on the first day of the academic school year.

D.1.2 Northern Ireland Curriculum in Northern Ireland

The Northern Ireland Curriculum is based on the National Curriculum in England with all students studying Primary Education between the ages of 5-11 and Secondary Education between the ages of 11-16. Unlike the education framework used in England, students in Northern Ireland do not need to remain in education or employment training until the age of 18, however the same options of Further Education are available to learners who choose to continue after the age of 16.

The main difference between the Northern Ireland Curriculum and the National Curriculum is in the naming of the school years. Whereas, the National Curriculum starts in Reception and then increments from Year 1 up to Year 13, the Northern Ireland Curriculum instead starts in Primary 1 and increments through Primary 7 and Year 8 up to Year 14. This means that an 11-year-old starting Secondary Education in Northern Ireland will enter Year 8, whereas in England and Wales the same 11-year-old will instead enter Secondary Education in Year 7. The other difference is in when a child enters each stage of education: in Northern Ireland it is determined by a child's age on July 1st, however in England and Wales it is instead determined by a child's age on September 1st. These subtle differences aside, the Northern Ireland Curriculum system also uses the same system of GCSEs, AS-Levels and A-Levels as the National Curriculum and a child will study a wide range of subjects including Mathematics, English and Science being compulsory.

Table D.2 | An overview of the key stages of the Northern Ireland Curriculum framework used in Northern Ireland.

School Age	School Year	Stage	Description
4	Primary 1	Foundation Stage	Primary Education
5	Primary 2	Foundation Stage	Primary Education
6	Primary 3	Key Stage 1	Primary Education
7	Primary 4	Key Stage 1	Primary Education
8	Primary 5	Key Stage 2	Primary Education
9	Primary 6	Key Stage 2	Primary Education
10	Primary 7	Key Stage 2	Primary Education
11	Year 8	Key Stage 3	Secondary Education
12	Year 9	Key Stage 3	Secondary Education
13	Year 10	Key Stage 3	Secondary Education
14	Year 11	Key Stage 4	Secondary Education
15	Year 12	Key Stage 4	Secondary Education - GCSEs
16	Year 13	Key Stage 5	Further Education - AS-Levels
17	Year 14	Key Stage 5	Further Education - A-Levels

Note: School age specifies the age of the student on the first day of the academic school year.

D.1.3 Curriculum for Excellence in Scotland

Scotland uses the Curriculum for Excellence which is a separate framework to the rest of the UK. It consists of three main assessments named *Nationals*, *Highers* and *Advanced Highers* which are approximately equivalent to the National Curriculum's GCSEs, AS-Levels and A-Levels respectively.

Unlike the rest of the UK, there are only two distinct levels of education in Scotland between the ages of 5-18: Primary Education which consists of seven years (P1-P7); and Secondary Education which consists of six years (S1-S6). Years P1 to P7 and S1 to S4 are mandatory and at the end of S4, students will sit their final National examinations. S5 and S6 are optional and students who opt to continue with their education will do their Higher examinations in S5 and may choose to continue to do their Advanced Higher examination in S6. The Higher qualifications are what students in Scotland need to apply to university. Unlike the rest of the UK, the Advanced Highers are equivalent to a first year of university, from which students can opt to use these qualifications to apply to enter their second year of university.

D.1.4 Higher Education System in Scotland

Scotland has a slightly different Higher Education structure to England, Wales and Northern Ireland, where an undergraduate degree course can comprise of up to four years of study:

Year 1: Students have the option to study up to three subjects within a particular faculty (e.g., science or arts).

Year 2: Students can continue with the same three subjects or change to different subjects within the same faculty.

Year 3: Students choose to continue with just one of the subjects which they studied in Year 1 or Year 2.

Year 4: Students complete their study with the subject which they chose in Year 3.

As described in Section D.1.3, students studying Secondary Education in Scotland have the

Table D.3 | An overview of the key stages of the Curriculum for Excellence framework used in Scotland.

Note that whilst the school age has been given in the table below, the design of the Curriculum for Excellence is such that students can move through it at their own pace. For example, an able student may progress through the levels faster than their peers.

School Age	School Year	Level	Description
5	P1	Early Level	Primary Education
6	P2	First Level	Primary Education
7	P3	First Level	Primary Education
8	P4	First Level	Primary Education
9	P5	Second Level	Primary Education
10	P6	Second Level	Primary Education
11	P7	Second Level	Primary Education
12	S1	Third/Fourth Level	Secondary Education
13	S2	Third/Fourth Level	Secondary Education
14	S3	Third/Fourth Level	Secondary Education
15	S4	Senior Phase	Secondary Education - Nationals
16	S5	Senior Phase	Secondary Education - Highers
17	S6	Senior Phase	Secondary Education - Advanced Highers

Note: School age specifies the age of the student on the first day of the academic school year.

option to study Advanced Highers. Advanced Highers can form the basis of Year 1 of Scottish Higher Education and so successful completion of Advanced Highers can mean that students can enter university into Year 2, and thus only complete three years of Higher Education which is akin to the Higher Education system seen in the rest of the UK. Due to these differences, the average age of students starting in Scottish universities is typically 16 or 17, whereas the average starting age is 18 or higher in the rest of the UK. The advantage of the Higher Education system in Scotland is that learners have some degree of flexibility to change their degree course to suit their needs and interests up to the start of Year 3. In comparison, the Higher Education system in the rest of the UK requires learners to choose a single subject to study at the start of Higher Education and complete three years of study with this one subject; whilst there may be some degree of flexibility to change to a closely-related subject, in most cases students will have to restart from Year 1 again if they wish to change to a different subject. This puts the Scottish Higher Education system at an advantage by offering students more flexibility to study a wider range of subjects across the duration of their undergraduate degree at university.

D.2 First-Year Undergraduate Modules at the University of Essex which Involve Quantitative Skills

This subsection lists the modules taught at the University of Essex in the academic year 2022-2023 which we deem to involve quantitative skills. This list was compiled by firstly searching each department timetable and filtering by first-year undergraduate modules to source an exhaustive list of all modules taught to first-years in all departments. Since the University of Essex has three campuses, we chose modules which were taught at the Colchester campus as this was the target of our study. This gave 244 modules from 18 departments which we then manually searched using the unique module code on the respective web page to source the module content. We then looked for keywords or phrases which we deemed to relate to quantitative skills. This gave 77 modules from 10 departments with an broad overview of the quantitative skills that would be necessary within that module. Note that whilst we could have conducted a formal survey to obtain further detail about the content which would be taught on each module, we elected to use the approach described here as a convenient way to estimate the amount and type of quantitative content which would be taught to our target demographic.

Table D.4 | School of Computer Science and Electronic Engineering (3 of 15 first-year undergraduate modules involve quantitative skills = 20%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
CE141	Mathematics for Computing	Au+Sp+Su	Propositional logic, combinatorics, set theory, probability, vectors and matrices.
CE142	Mathematics for Engineers	Au	Calculus (integration and integration), functions (trigonometric, logarithmic, exponential), vectors and matrices, complex numbers, Fourier series.
CE171	Neural Engineering Research Methods	Sp+Su	Inferring results from data, hypothesis tests.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.5 | Department of Economics (5 of 7 first-year undergraduate modules involve quantitative skills = 71%).

Module			Quantitative Skills
Code	Name	Teaching Term(s)	
EC101	Business Economics	Au	Numeracy skills
EC111	Introduction to Economics	Au+Sp+Su	Macroeconomics, microeconomics, marginal analysis.
EC114	Introduction to Quantitative Economics	Au+Sp+Su	Construct and interpret graphs of data, summary statistics, economics models, hypothesis tests.
EC115	Methods of Economic Analysis	Au+Sp+Su	Fundamental mathematical concepts essential for solving economics problems.
EC116	Applied Economics and Policy	Au+Sp+Su	Analysis of data within economics, testing economic models with data.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.6 | Edge Hotel School (4 of 11 first-year undergraduate modules involve quantitative skills = 36%).

Module			Quantitative Skills
Code	Name	Teaching Term(s)	
EG120	Finance for Events/Hospitality Business	Au+Sp+Su	Interpret and construct financial documents from data (balance sheets, industry benchmarks), use key performance indicators (KPI) for monitoring budget and performance, micoreconomics, use live data and report on performance.
EG121	The Event/Hospitality Business Environment	Au+Sp+Su	Demonstrate size of sector (turnover, assess economic contributions).
EG125	Hospitality Operations	Au+Sp+Su	Develop pricing strategies based on KPIs and balance sheets.
EG127	Events Operations	Au+Sp+Su	Understand and interpret financial concepts and documents, calculate and interpret operational ratios.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.7 | Essex Business School (18 of 20 first-year undergraduate modules involve quantitative skills = 90%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
BE102	Intro to Accounting I	Au	Financial reporting, costing, financial analysis.
BE103	Intro to Accounting II	Sp+Su	Finance, accounting equations and principles.
BE110	Financial Reporting and Analysis	Au+Sp+Su	Financial accounting.
BE111	Management Accounting I	Au+Su	Cost management, accounting.
BE113	Management Accounting II	Sp+Su	Costing systems and costing control, analyse data.
BE120	Audit Principles and Practice	Sp+Su	Understand sales and payroll systems, finance.
BE130	Current Issues in Financial Reporting	Au+Sp+Su	Evaluate financial statements and accounting standards.
BE131	Advanced Management Accounting	Au+Su+Sp	Technical, analytical and evaluation skills of accounting techniques.
BE132	Auditing	Sp+Su	Understand and critique auditing practices.
BE133	Critical Debates in Accounting	Sp	To understand and critique accounting practices.
BE142	Taxation Policy and Practice	Sp+Su	Compare and contrast taxes paid by individuals and organisations.
BE150	Issues in Financial Reporting	Au+Su	Understand and critique accounting and financial practices.
BE151	Management Accounting	Au+Su	Understand strengths and limitations of management accounting and costing.
BE154	International Management Accounting	Sp	Understanding changing management practices.
BE155	International Financial Reporting	Sp	Understand main types of financial reporting systems.
BE161	Corporate Reporting and Analysis	Au+Su	Financial performance measures, ratios in decision models, accounting methods for financial statements.
BE162	Financial Decision Making	Au+Su	Costing and profit analysis, financial and economic principles.
BE167	Accounting and Finance for Managers	Au+Sp	Analyse financial reporting measures, budgeting.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.8 | Essex Pathways Department (14 of 30 first-year undergraduate modules involve quantitative skills = 47%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
IA102	Introduction to Biology	Au+Sp+Su	Analysis and interpretation of scientific data.
IA106	Introduction to Economics	Au+Sp+Su	Solve economic questions mathematically.
IA112	Essential Mathematics	Au+Sp+Su	Algebraic equations, curves, calculus, trigonometric functions, sequences and series.
IA115	Mathematical Methods and Statistics	Au+Sp+Su	Summary statistics, sampling data, probability, probability distributions, hypothesis testing, vectors, kinematics, Newton's laws, forces, moments, complex numbers, numerical methods.
IA119	Computers and Electronics	Au+Sp+Su	Work with different number systems, logic.
IA123	Chemistry for Biology	Au+Sp+Su	Perform calculations, interpret and analyse scientific data.
IA124	Mathematics and Statistics for Economics and Business	Au+Sp+Su	Arithmetic, algebra, graphs, calculus, summary statistics, normal distribution, hypothesis tests.
IA126	Mathematics for Computer Science	Au+Sp+Su	Arithmetic, algebra, number systems, graphs, convergence and divergence of series, calculus, propositional logic, trigonometry, combinations and permutations.
IA127	Statistics for Psychology	Au+Sp+Su	Sampling methods, statistical summaries, statistical graphs, normal distributions, probability, hypothesis tests, correlation and regression.
IA128	Maths and Statistics for Biological Sciences	Au+Sp+Su	Arithmetic, algebra, graphs, calculus, units, summary statistics, types of statistical variables, graphing data, probability, normal distribution, hypothesis tests.
IA129	Datacy	Au+Sp+Su	Types of data for social science, hypotheses and research questions, sampling data, hypothesis testing, interpreting analysis outputs, presenting data, criticising data presentation techniques.
IA174	Introduction to Accounting and Finance	Au+Sp+Su	Financial analysis and interpretation.
IA177	Introduction to Anatomy and Physiology	Au+Sp+Su	Analyse and present scientific data.
IA178	Introduction to Biomechanics	Au+Sp+Su	Trigonometry, vectors, numerical methods, kinematics (linear and angular), Newton's laws, forces, analyse and present scientific data, potential and kinetic energy.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.9 | School of Life Sciences (9 of 14 first-year undergraduate modules involve quantitative skills = 64%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
BS111	Plant Biology and Ecosystems	Sp+Su	Analysing and presenting data through lab work.
BS112	Marine Ecology	Au+Su	Analysing and presenting data through lab work.
BS113	Animal Evolution, Ecology and Behaviour	Au+Su	Analyse and interpret biological data.
BS114	Marine Biology Field Skills	Au+Sp	Data handling and analysis
BS131	Biochemistry of Macromolecules	Sp	Data analysis, interpretation and presentation.
BS132	General and Organic Chemistry	Au+Sp+Su	Demonstrate competence in data analysis and interpretation.
BS133	Inorganic and Physical Chemistry	Sp+Su	Basic skills in numeracy by using chemical formulae and equations, data analysis.
BS141	Quantitative methods for Life Sciences	Au+Sp	Linear equations, exponentials and logarithms, calculus, solve scientific equations, presenting data, summary statistics, sampling data, types of variables, normal distributions, hypothesis tests, presenting data.
BS161	Anatomy and Physiology	Au+Su	Analyse and present data.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.10 | Department of Mathematical Sciences (9 of 11 first-year undergraduate modules involve quantitative skills = 82%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
MA101	Calculus	Au+Sp+Su	Rules of differential and integral calculus, functions, inequalities, first and second order ODEs, l'Hopital's rule, stationary points, partial differentiation, double integrals, power series.
MA105	Mechanics and Relativity	Sp+Su	Vectors, Newton's laws of motion, Hooke's law, simple harmonic motion, friction, conservation of energy, work.
MA108	Statistics I	Sp+Su	Summary statistics, presenting data, probability, probability distributions, types of variables, central limit theorem.
MA111	Foundational Mathematics for Data Science	Au+Sp	Functions and their graphs, differential and integral calculus, vectors and matrices, distance metrics.
MA114	Matrices and Complex Numbers	Au+Sp+Su	Complex number artithmetic, plotting complex numbers, Cartesian and polar forms, arguments and moduli, complex roots, geometric and algebraic properties of vectors, operations on matrices, solving linear equations using matrices, eigenvalues and eigenvectors, diagonalising a symmetric matrix.
MA125	Introduction to Geometry, Algebra, and Number theory	Sp+Su	Circle theorems, trigonometric identities, arithmetic and geometric progressions, Euclidean algorithms, primes and divisors, remainder and rational root theorems, general solution of cubics, modular arithmetic, solution of linear congruences, linear Diophantine equations, Fermat's lemma.
MA127	Economics for Actuaries	Au+Sp+Su	Economic concepts, costings, profit maximisation, exchange rates, interest rates, the financial system, macroeconomics, microeconomics.
MA181	Discrete Mathematics	Au+Su	Sets, relations, functions, induction and recursion, logic.
MA185	Mathematical and Computational Modelling	Au+Su	Programming, mathematical modelling.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.11 | Department of Psychology (6 of 8 first-year undergraduate modules involve quantitative skills = 75%).

Module			Quantitative Skills
Code	Name	Teaching Term(s)	
PS101	Understanding our place in the world	Au	Present data from a psychology experiment.
PS102	Growing in the world	Au	Describe and graphically represent the relationship between continuous variables.
PS103	Experiencing Emotion	Au	Interpret quantitative information (e.g., in graphs, figures and tables) and demonstrate understanding of key statistical concepts around measurement and variability.
PS104	Thinking and the Mind	Sp	Hypothesis testing.
PS105	The Social World	Sp	Analyse and interpret quantitative relationship between two variables.
PS106	The Social Brain	Sp	Statistical procedures to analyse differences, present data.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.12 | Department of Sociology (2 of 7 first-year undergraduate modules involve quantitative skills = 29%).

Module			Quantitative Skills
Code	Name	Teaching Term(s)	
SC101	Researching Social Life I	Au+Sp	Quantitative data analysis.
SC104	Introduction to Crime, Law and Society	Au+Sp+Su	Critically evaluate crime data.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

Table D.13 | School of Sport, Rehabilitation and Exercise Science (7 of 15 first-year undergraduate modules involve quantitative skills = 47%).

Module			Quantitative Skills
Code	**Name**	**Teaching Term(s)**	
SE101	Professional Skills and Development 1	Au+Sp	Data processing, statistical tests to analyse data.
SE102	Biomechanics	Sp	Mechanics for movements of human body and objects in sports, Newton's laws of motion, data analysis and presentation.
SE103	Principles of Nutrition and Metabolism	Sp	Data analysis and presentation, numerical calculaltions
SE105	Anatomy and Physiology	Au+Sp	Data analysis and presentation, numerical calculations.
SE106	Introduction to Sports and Exercise Science	Au	Use scientific equipment to collect, analyse and present data.
SE111	Anatomy and Physiology for Coaches	Au	Numerical calculations.
SE136	Introduction to Performance Analysis	Sp	Understand data collection and sampling issues, data visualisation.

Au = Autumn term (beginning of October until the middle of December), *Sp* = Spring term (middle of January until the middle of March), *Su* = Summer term (middle of April until beginning of June).

D.3 University Statements on Core Mathematics

This subsection lists the university statements about Core Mathematics available to prospective students on their admissions pages. We utilised the list given in Glaister (2015b) and, where possible, searched the university web pages in February 2023 to update this. Some universities had web pages which were difficult to navigate and so we failed to find messaging relating to Core Mathematics. In such instances, we chose to use the previous statements listed by the author. We then synthesised these statements in Table 3.5 to show which universities offered a reduction in entry requirements or accepted Core Mathematics as an alternative for a Level 2 or Level 3 mathematics qualification. Some universities (e.g., University of Newcastle, University of Leeds, University of Leicester, University College London) specified that Core Mathematics would only be accepted as meeting the GCSE Mathematics requirements for the course if a pass grade had also been achieved in GCSE Mathematics. Some other universities (e.g., University of Newcastle, University of Durham, University of Edinburgh, King's College London, University of Bristol) stated that specific grades in Core Mathematics need to be achieved in order to qualify for an alternative to GCSE Mathematics. University of Durham also specified that Core Mathematics would only be accepted in lieu of GCSE Mathematics on specific degree courses.

University of Manchester

The University welcomes and recognises the value of Level 3 core mathematics qualifications (e.g. AQA Certificate in Mathematical Studies). Core Mathematics is not a compulsory element of post-16 study and as a result we will not normally include it in the conditions of any offer made to the student. However, if a student chooses to undertake a core mathematics qualification this may be taken into account when we consider their application, particularly for certain non-science courses with a distinct mathematical or statistical element. We advise students to contact the academic School, who will clarify whether their specific portfolio of qualifications is acceptable for entry on to their chosen course.

London School of Economics, University of London

Core Maths may add value to an application, similar to the EPQ, in particular where the programme has a specific mathematical content but does not require a specific maths qualification e.g. Psychology or Geography. Core Maths cannot be used as a replacement for A level Maths (or equivalent qualifications) for programmes with a maths A level requirement. Core Maths can be considered as an alternative way to meet the standard LSE GCSE maths requirement (Grade B/6).

Queen Mary, University of London

We welcome the introduction of the new Core Maths qualifications and believe they will be beneficial to students wishing to study Social Science subjects that may involve the use of applied mathematical skills, such as Business Management, Geography, and Politics. We may consider the Core Maths qualification *in lieu of the GCSE Mathematics requirement for your chosen course. Please list Core Maths as one of the qualifications you are taking when you apply through UCAS.*

University of Southampton – (Glaister, 2015b)

We welcome the introduction of the new Core Mathematics qualification in England and fully support the principles behind the new qualifications. We believe they could be beneficial to students considering making an application to a range of degree subjects in the social sciences, business, and health sciences, for example. Applicants not taking mathematics to A or AS level are advised to include their Core Mathematics qualification on their UCAS application form, especially if they are applying for degrees in subjects such as social sciences, business and geography, for which A/AS mathematics is not a requirement. However, we will not make Core Mathematics an entry requirement as this qualification is not available universally.

University of Exeter

The University values students studying the Extended Project and/or Core Maths and its role in preparing students for a successful higher education experience and would wish to recognise and encourage this extended piece of independent work undertaken by the learner. In recognition of this, for students who receive a standard offer, make Exeter their Firm choice and achieve a grade A in either the EPQ or Core Maths we guarantee to confirm their place if they achieve 1 grade below our offer, excluding any subject conditions. *excludes contextual offers*

Lancaster University

Core Maths will not typically form part of the offer for entry to Lancaster, but we will accept it as meeting the equivalent of a GCSE Mathematics requirement.

University of Birmingham – (Glaister, 2015b)

Where a programme requires above a grade C in GCSE Mathematics or an AS level in Mathematics it is probable that we will consider the level 3 Core Maths qualification as meeting these requirements.

Loughborough University

Core Maths may be useful for a range of degree subjects where enhanced numerical or statistical skills are beneficial. However, Core Maths is not equivalent in size to an A level and therefore is not a suitable replacement for A level Maths where this is a required subject.

Aston University – (Glaister, 2015b)

Whilst we would not discriminate against students who do not/are unable to take a Core Maths course from 2015 we welcome the ethos behind this development. For example, students in social sciences, business, psychology, sciences and health sciences who are not taking A/AS level Maths may find the Core Maths element useful in preparing for university study where a working application of maths or statistics may be required.

Royal Holloway, University of London – (Glaister, 2015b)

The Core Maths qualification is accepted alongside GCSE Maths for those programmes requiring a minimum of a grade B in GCSE Maths. e.g. Psychology

Coventry University

We welcome the introduction of Core Mathematics and would be pleased to receive applications from students offering these qualifications. Core Mathematics will not typically form part of any offer for entry to Coventry, unless specified as a subject requirement at individual degree level.

Leeds Beckett University – (Glaister, 2015b)

We will not require Core Maths as a specific qualification for entry, though we support this development as a useful preparation for university study.

University of York

We welcome the introduction of the Core Maths qualifications and recognise the benefits that they bring, not only to university study, but also to future employment. In acknowledgement of this, some of our departments will make a reduced offer where a Core Maths qualification is taken alongside three A levels or equivalent. Core Mathematics will however not be acceptable as a substitute for an A level Mathematics requirement.

University of Newcastle – (Glaister, 2015b)

We welcome the introduction of Core Maths qualifications and believe that they will be of benefit to students who take degree programmes which involve quantitative skills but do not require A or AS level Mathematics. Some of our degree programmes require GCSE Mathematics from applicants who are not taking Mathematics at A level or equivalent, usually at grade A or B. We will accept a Core Mathematics qualification (minimum grade C) in lieu of the required GCSE Mathematics grade where an applicant has achieved grade C or 4 in the GCSE. In some cases, we may make a dual offer to take account of a Core Mathematics qualification.

University of Hull – (Glaister, 2015b)

We support the ethos behind Core Maths and such study may be beneficial to students in a wide range of degree programmes. However, we know there may be restrictions on student choice and will not make this a requirement. Core Maths is not a suitable replacement for those programmes at Hull that require A level maths.

University of Buckingham

While we would not discriminate against students who do not/are unable to take a Core Maths course from 2015, we welcome the ethos behind this development. For example, students in social sciences, business, psychology and sciences who are not taking AS/A Level Maths may find the Core Maths element useful in preparing for university study where a working application of maths or statistics may be required.

Nottingham Trent – (Glaister, 2015b)

As of September 2014 a new suite of mathematical qualifications (equivalent to an AS level) have been introduced to encourage the continuation of mathematical study post 16: The University will accept Core Maths in lieu of GCSE for courses which have historically required a Maths grade C or above.

University of Sunderland – (Glaister, 2015b)

The University of Sunderland welcomes the New Core Maths qualification and will accept this qualification, where possible in lieu of GCSE Mathematics grade C or above.

University of Surrey – (Glaister, 2015b)

The University of Surrey supports the ethos behind this new qualification in that it may be beneficial to a range of degree subjects that do not generally ask for A-level Mathematics but where enhanced numerical or statistical skills may be helpful. For this reason, we encourage applicants to consider taking this qualification where practical. However, we are aware that the school curriculum and/or timetabling may prohibit this, so we will not be including Core Mathematics as part of a conditional offer unless the applicant has presented with in this in lieu of another equivalent qualification.

University of Warwick

The University of Warwick welcomes the development of the core maths qualifications, and the additional relevant skills that the qualifications can provide in preparation for a range of our courses. In some cases, departments would be happy to take the qualification in lieu of their GCSE mathematics requirement, but please refer to the individual entry requirements for the course in which you are interested.

University of Bath

For admissions to the University of Bath from 2020 onwards, there will be greater recognition of level 3 maths qualifications through the use of alternative offers. These alternative offers reduce one of the entry grades required; for example, where the typical A level offer is AAA, the alternative offer would be AAB. The University of Bath recognises that quantitative and analytical skills are invaluable to a range of degree courses, and that extra experience beyond the essential requirements of the course can be beneficial to students' future studies. All degrees that do not require A level Mathematics, such as Architecture, Business Courses, Biosciences, Chemistry, Pharmacy, Education, Health and Sport degrees, Languages, Politics, Psychology, and Social Sciences, will include alternative offers based on achieving a grade B in a Core Maths qualification, AS or A level Mathematics or AS or A level Statistics, when it is studied in addition to three other subjects. Degrees that do require A level Mathematics, such as Civil, Chemical, Mechanical and Electrical Engineering, Computer Science, Physics, Economics and Accounting & Finance, will include alternative offers based on achieving a grade B in AS or A level Further Mathematics where this is studied in addition to three other subjects.

Harper Adams University

The University welcomes the introduction of the new suite of Core Mathematics qualifications and believes that, where accessible, it will be beneficial for students to study alongside their other level 3 qualifications, where there is a need to develop their skills in this area. There is no requirement for applicants to study the qualification and we will not be able to consider it as a substitute for A level Mathematics, for courses which require it. However, unless specifically excluded, where general tariff point offers are made for course entry, the qualification will be included towards the required tariff points.

University of Kent

Kent welcomes the introduction of Core Mathematics qualifications to provide students with the opportunity to develop their mathematical skills beyond GCSE. As the University is a nationally recognised Q-Step centre for quantitative social science skills, we value the importance of giving our students the chance to develop broader statistical, problem-solving, evaluation and data analysis skills. We believe students taking degree subjects that do not require an A level in Mathematics benefit from taking a Level 3 Core Mathematics qualification from the suite available. Although not a prerequisite for admission, we would continue to look positively on applications from students offering Core Mathematics qualifications.

University of Sheffield

Core Maths qualifications specifically focus on the use of mathematics skills in contextualised, complex scenarios. The University of Sheffield welcomes the ethos behind the development of Core Maths and recognises that students who are not taking AS or A Level Maths may find these qualifications beneficial in preparing for undergraduate study, even if the course does not require AS or A Level Maths as part of the entry requirements. We welcome the evidence of breadth of study and skills development that studying Maths post-16 level can provide. Where a Core Maths qualification is presented alongside three A Levels or equivalent, we may be able to issue an alternative offer as part of our Access Sheffield scheme. We will not accept Core Maths in lieu of A Level Maths where this is a specified requirement for entry.

University of Essex

Although Core Maths will not typically form part of any offer made by the University of Essex, we welcome the introduction of this new qualification. We believe that it will provide valuable preparation for university study, particularly those wishing to study courses which involve the use of statistical data such as the social sciences.

Goldsmiths, University of London

Core Maths qualifications will be looked upon favourably for degrees where there is a maths requirement, but we cannot accept it in lieu of a full A-level.

University of Leeds

We will accept Level 3 Core Maths if you have achieved a grade C/4 in GCSE Maths but you need a higher grade for your chosen course. Where A-level Maths is required we do not accept Core Maths instead.

University of Leicester – (Glaister, 2015b)

We welcome the new Core Maths qualification but recognise that not all schools and colleges will offer the qualification at this time. It will not typically form part of an offer but will be considered alongside other qualifications. For those programmes where grade B (5) in Maths GCSE is a requirement, grade C in Core Maths is an acceptable qualification.

Cardiff University – (Glaister, 2015b)

Cardiff University recognises the benefits of the Core Mathematics qualification, particularly in helping students to use and develop mathematical modelling and problem solving skills, which are key not only to University study but to employers. Whilst Core Mathematics is not a requirement for entry into Cardiff University, it may be considered in lieu of a GCSE in Mathematics at grade B or above, but will not be accepted in lieu of an AS or A-Level in Mathematics where this is required.

University College London – (Glaister, 2015b)

Core Mathematics programmes are designed for students who have achieved a grade A- C in GCSE, who are not taking the subject to AS or A level, but who wish to continue studying Mathematics beyond GCSE. Whilst the qualification does not form part of our standard entrance requirements, UCL welcomes the opportunity for students to be able to continue their mathematics studies. For programmes where GCSE Mathematics is required at grade B, Core Mathematics will be accepted as a supplement to grade C at GCSE.*

University of Liverpool

The University recognises the value of the Core Maths qualification to support the development of mathematical skills. While the University will not include Core Maths in our entry requirements, we welcome the additional skills it will give to students. We will not accept Core Maths in lieu of AS/A level Maths or equivalent qualifications where Mathematics is a subject requirement.

Sheffield Hallam University – (Glaister, 2015b)

Sheffield Hallam University supports the introduction of the new Core Maths qualification and the additional skills this will provide for those who are able to access it, however we will not be requiring this as a condition of entry to our courses.

University of Brighton – (Glaister, 2015b)

The University of Brighton fully supports the ethos behind the introduction of the new Core Mathematics qualifications and believes they could be beneficial to students considering making an application to a range of degree subjects. However, the University does not intend, at this time, to set an expectation that such applicants must offer this new qualification nor for Core Mathematics to be a substitute for where A level Mathematics is specified in an offer.

City, University of London – (Glaister, 2015b)

City, University of London welcomes the introduction of Core Maths and recognises the benefit that it will bring for students who require quantitative skills but do not require A level Mathematics. Many of our courses, especially in the area of Social Sciences and Business, will appreciate the broader statistical, numerical and problem-solving skills that it develops. Please note that for courses in Engineering or other disciplines where Mathematics A level may be a requirement, Core Maths will not be considered as an equivalent.

University of Durham – (Glaister, 2015b)

We particularly welcome the introduction of the Core Mathematics Qualification and we will accept a Core Maths Qualification (grade B minimum) in lieu of our grade A in GCSE Mathematics requirement for programmes in accounting, business, finance, management, and marketing.

University of Edinburgh

Core Maths at a grade A will also be accepted in place of GCSE Mathematics at a grade A and at a grade B in place of GCSE Mathematics at a grade B. Core Maths will not be accepted in place of AS or A-Level Mathematics.

Imperial College, London – (Glaister, 2015b)

Imperial College London supports the introduction of the Core Maths qualification and recognises its value to students. However, this will not be accepted in lieu of AS/A-level Maths or Further Maths.

University of Reading – (Glaister, 2015b)

In England, a new 'Core Maths' qualification was introduced in September 2014 with the intention of increasing the number of people who study mathematics beyond GCSE level. This qualification focuses on the use of mathematics skills in contextualised, complex scenarios. The University of Reading supports and values the ethos behind this qualification and recognises that it may be beneficial to a range of *degree subjects that do not generally ask for AS or A Level Mathematics but where enhanced numerical or statistical skills may be helpful. Core Maths is not a compulsory element of post-16 study and we are not currently able to accept Core Maths in lieu of AS or A Level Mathematics where this is a specified requirement for entry. However, whilst we do not, at this time, include it as a formal condition of an offer to our applicants, we do welcome the evidence of breadth of study and skills development that studying mathematics at post-16 level can provide.*

University of Nottingham

While we welcome the additional breadth of study that Core Maths can bring to an application, we do not accept the Core Maths qualification in place of A-level Mathematics in our entry requirements. However, we will consider it to meet mathematics requirements in place of GCSE's.

King's College London

We recognise that Core Maths qualifications have the potential to develop a level of mathematical skill that would be beneficial for studying many of our undergraduate programmes, and we will accept Core Maths in lieu of any required maths grade at GCSE, using the below equivalencies. However, where maths is a required subject at A level, we would not consider Core Maths to be a suitable alternative for meeting this requirement. King's has agreed the following grade equivalencies: GCSE A/8 = CM A; GCSE A/7 = CM B; GCSE B/6 = CM C; GCSE C/5 = CM C*

University of Cambridge

While we recognise the value of Core Maths in strengthening mathematical ability and, where appropriate, encourage students to take Core Maths, please note that it isn't a suitable alternative to A Level/IB Higher Level Mathematics and won't be a requirement of any offer made. You may use your Core Maths grade as part of meeting the UCAS tariff for the Foundation Year, but we would expect it to be combined with your other qualifications to meet the total tariff required.

Keele University

Applicants undertaking the following qualifications will receive two offers when they apply to Keele, a standard offer and an alternative offer. You will only need to meet the requirements of one of these offers to qualify for entry. The following table is provided as a guide to how our standard offers will be adjusted to account for additional qualifications. If you are not certain how or whether this would apply to you, please contact us and we will be happy to confirm: 1 grade reduction if A in Core Maths for Medicine; 1 grade reduction if B in Core Maths for Physiotherapy, Radiography, Paramedic Science, Pharmacy, Social Work, Nursing, Midwifery; 2 grade reduction if B in Core Maths for all other courses (not Vetinary Medicine).

University of Plymouth

The University of Plymouth welcomes the introduction of the Core Mathematics qualification. We believe it will provide valuable preparation for university study and would encourage its uptake and inclusion on an applicant's UCAS form, particularly for students wishing to apply for courses that involve the use of statistical data and where a Mathematics 'A' level is not part of the standard offer. We are not able to accept Core Mathematics in lieu of AS or A level mathematics where this is a specified requirement for course entry.

University of Central Lancashire

The University of Central Lancashire (UCLan) supports the introduction of the new Core Maths qual-

ification and recognises the benefits it can bring to students across a breadth of degree courses. As an institution with a strong track record of widening educational access to under-represented groups, Central Lancashire is keen to accept a broad range of qualifications to support this including Core Maths.

University of Bristol

We do not accept Core Maths in place of A-level Mathematics in our entry requirements. Core Maths can be used to meet our numeracy requirements instead of GCSEs; required grades and other acceptable qualifications can be found on our GCSE profile requirements web pages.