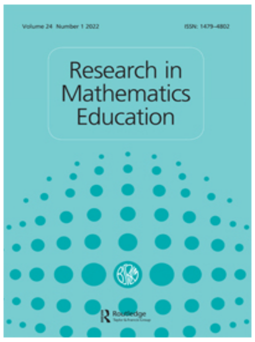

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"I was told it would help with my Psychology": Do post-16 Core Maths qualifications in England support other subjects?

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ABSTRACT
Continuing to study mathematics throughout schooling is considered important in most developed countries, where mathematics is incorporated within the curriculum until school-leaving age. By comparison, in England, relatively few post-16 (upper secondary) students study mathematics once it becomes optional. Core Maths qualifications, introduced in England in 2014, are intended to help increase post-16 mathematics participation. This paper uses data from a three-year, mixed-methods, longitudinal study to investigate a perceived benefit of the qualifications: the support Core Maths might give to other curriculum subjects in post-16 students' programmes. Amongst teachers and students, we find a widespread conviction that studying Core Maths benefits students' other subjects contemporaneously, whilst in national data from Core Maths students we find no evidence yet of enhanced examination attainment in other qualifications. We suggest that Core Maths impacts positively on students in ways which could be more usefully, and accurately, emphasised in promoting the course.

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Core Maths; post-16 mathematics; post-16 education policy; post-16 curriculum

Introduction

Mathematics underpins all scientific disciplines and technical fields. Adequate preparation in mathematics is therefore essential for students wishing to forge careers in science, technology, engineering and mathematics (STEM) (McAlinden & Noyes, 2019b; Noyes, Wake, & Drake, 2011). Moreover, the increasing quantitative demand across numerous social, commercial, business and scientific endeavours (Noyes & Adkins, 2016) renders quantitative skills essential in areas ranging from engineering to business studies, from psychology to sociology, even art (Brown, Brown, & Bibby, 2008; Smith, 2017).

In higher education (HE) too, the quantitative demands of many courses are considerable, with statistics, in particular, becoming widely taught (Hodgen, McAlinden, & Tomei, 2014). Finally, critical and thoughtful citizenship requires questions to be asked with, and of, data, looking beyond superficial interpretations, to provide robust judgements and inferences within specific contexts (Crowe, 2010; Geiger, Forgasz, &

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Goos, 2015). This global societal need has been brought into relief by the COVID-19 pandemic, as graphical and numerical data have underpinned the UK and other governments' justification of their policy responses.

In this paper, we explore the perceived benefits of a new mathematics qualification introduced in England in 2014 for 16- to 18-year-old students. We begin by setting out some of the background which will illuminate the current context.

Low post-16 mathematics participation in England, and its consequences

In most developed countries, the opportunity to study mathematics is widely available, as an option or a compulsory subject, through upper secondary education (in England, the post-16 phase), until students leave full-time education, usually at the age of around 18, to go into university, apprenticeship or employment. The four UK nations lag behind international competitors, in terms of post-compulsory continuation rates in mathematics (Hodgen, Pepper, Sturman, & Ruddock, 2010; Noyes & Adkins, 2016). A decade ago, England was named as having the lowest rate in the developed world of students pursuing advanced (Level 3) mathematics after taking the compulsory Level 2 General Certificate of Secondary Education (GCSE) at 16: typically, only around a fifth of students take Level 3 mathematics (Hodgen et al., 2010).

This concern with, and scrutiny of, the number and proportion of students participating in post-16 mathematics is long-running (Noyes & Adkins, 2017; Smith, 2004; The Royal Society, 2008). Concerns have been expressed by mathematics education bodies, HE and employers that such low participation inhibits successful participation in, and contribution to, HE and employment, limits wider life skills, and affects the UK's ability to compete on the global stage (The Royal Society, 2008).

Levels of mathematical and scientific competence amongst England's school-leavers, undergraduates and graduates, and their ability to transfer knowledge between contexts, are regarded as insufficient for competent performance in a range of fields; undergraduates have displayed anxiety around numeracy (British Academy, 2015; Chapman, 2010; Crowther, Thompson, & Cullingford, 1997; Hoban, Finlayson, & Nolan, 2013). The Advisory Committee on Mathematics Education (ACME, 2011) attempted to quantify the extent of the problem in England (and other UK nations), estimating that over 200,000 students annually were admitted to undergraduate courses where they would have benefited from studying mathematics in the post-16 phase but had not done so. For example, 32% of students studying A-level Biology in 2016/2017 had not studied mathematics beyond GCSE (Smith, 2017). For many students, there was no suitable mathematics option. Before Core Maths was introduced, the most familiar, most frequently offered, and in most centres, the only, Level 3 mathematics option was to take A-level Mathematics, or to be assessed for AS[1] Mathematics after one year of A-level. However, A-level Mathematics is perceived as demanding, is only offered to the highest achievers, and contains advanced techniques, like calculus, that are not generally required for other post-16 subjects.

The lack of preparedness for mathematical HE programmes led to scrutiny of the mathematical content of a range of A-levels, and reports by SCORE (2012) and the Nuffield Foundation (2012) on the quantitative demands of Business Studies, Computing, Economics, Geography, Sociology and Psychology. These reports, and government reviews (Smith, 2013, 2014, 2017), resulted in calls for greater coherence across different awarding bodies, and across advanced mathematics and science qualifications (McAlinden & Noyes, 2019b).

Developing the right quantitative skills

Mathematics can mean advanced, more abstract mathematics, or (possibly for a wider group of students) courses emphasising mathematical literacy or general uses of mathematics (Hodgen et al., 2010). Different jurisdictions profess various reasons or rationales for privileging mathematics within their curriculum, engaging different motivating factors when persuading students to study mathematics: mathematics ability and qualifications stand for general intelligence and are key indicators of educational success; mathematics prepares students for life and work; mathematics helps other subjects; mathematical literacy helps citizens contribute to state and society; mathematics is an important part of our historical and cultural heritage; studying mathematics helps us think creatively outside the mathematics classroom (Skolverket, 2011; Smith & Morgan, 2016).

Students become more numerate as they increase their knowledge and skills, developing confident mathematical ability across learning areas at school and in their broader lives (Geiger et al., 2015). A broad view of mathematical knowledge, therefore, embraces higher-order thinking capabilities, such as problem-solving strategies and the ability to make sensible estimations (Zevenbergen, 2004).

All students, in sciences, social sciences or humanities, need to engage with appropriate tasks to develop the ability to analyse, interpret and present quantitative and statistical information, and reason with data, across the curriculum, enabling them to use and apply basic mathematical skills in problem-solving and critical assessment in different contexts, selecting appropriate procedures and techniques from contextual cues (British Academy, 2015; Hoyles, Wolf, Molyneux-Hodgson, & Kent, 2002; Noyes & Adkins, 2016; Quinnell, Thompson, & LeBard, 2013; Smith, 2017; Steen, 2001). The teaching of quantitative skills should therefore be a central component of education for students across all fields (British Academy, 2015; Smith, 2017). In particular, mathematical skills in the post-16 phase should feed into and support students' broader studies and qualifications, which then support employment, citizenship, and further study and development (Smith, 2017). Taking an example from another jurisdiction: in Sweden, all upper secondary students study mathematics, with several mathematics options tailored, in content and approach, to the broader programmes of students, whether sciences, humanities, arts, or technical programmes (Skolverket, 2011).

Increasing post-16 participation in England via changes to mathematics provision

Recognising the importance of mathematics for a number of reasons, and with a view to competing more successfully on the world stage, the UK government's stated ambition is for the "overwhelming majority" of young people in England to study mathematics to 18 (Department for Education, 2013). A twin policy strategy emerged of (i) *embedding* mathematics within other subjects, and (ii) *adding* new mathematics options to the curriculum offer (McAlinden & Noyes, 2019a). We address each in turn.

Embedding mathematics in other curriculum subjects

Recent reforms to A-level qualifications have seen mathematics and quantitative skills embedded into other academic and vocational subjects, following calls from HE and learned bodies (British Academy, 2016; MEI, 2016; Noyes & Adkins, 2017). This policy reflects the argument that students might learn mathematics more effectively when incorporated as part of their disciplinary studies (Adkins & Noyes, 2018). The changes aim to ensure that the mathematical demands of the disciplines are appropriately reflected in pre-university qualifications.

A third of non-mathematics A-levels now include more contextualised mathematics and statistics in synoptic assessments (Adkins & Noyes, 2018; Department for Education, 2014; Smith, 2017). A specified and mandatory percentage of the assessment now requires mathematical skills equivalent to Level 2 or above, the standard of higher tier GCSE Mathematics. This includes at least 10% of the assessment in A-level Biology and A-level Psychology, at least 20% in A-level Chemistry, and at least 40% in A-level Physics (Department for Education, 2014).

Adding a new course option: Core Maths

The Core Maths policy initiative is an explicit response to reports (e.g. ACME, 2011) and concerns that "Many entrants to university and employment do not have the mathematical skills expected of them" (Department for Education, 2015, p. 7). For students unable to access, or reluctant to take, A-level, there was generally no mathematics option. Core Maths qualifications, where offered, can now provide a more widely appropriate mathematics option.

Core Maths refers to a suite of post-16 application-focused, context-based qualifications, introduced in England in 2014 (Department for Education, 2013). Government documentation, for example, the technical guidance (Department for Education, 2018) and a policy statement (Department for Education, 2013), sets out aims and objectives for Core Maths qualifications, which address aspects of developing skills, confidence and fluency in using and applying mathematics. Core Maths is intended to support students with the mathematical demands of the varied contexts to which they will progress on leaving post-16 education (Department for Education, 2018, p. 5). In Core Maths lessons, mathematics and statistics can be applied to contexts and examples from Economics, Sociology, Psychology, and other subjects (Smith, 2017).

Policy documentation contrasts A-level Mathematics and Core Maths in terms of how each option supports students: A-level prepares students for higher-level study with a significant mathematical focus (engineering, economics, the sciences), whilst Core Maths students will be entering further study or careers in areas (geography, business, the social sciences) which do not have such a specific mathematical focus, but where mathematical knowledge and its application remain important. Thus, the documentation connects Core Maths explicitly with particular curriculum areas and employment types.

Notably, during the development of Core Maths qualifications, it was considered that Biology, but not Chemistry, might be best served mathematically by studying Core Maths rather than AS/A-level Mathematics (Browne et al., 2013) due to Core Maths's focus on consolidating GCSE Mathematics, problem-solving, and statistics. That said, for students not intending to pursue Chemistry beyond A-level, studying Core Maths is preferable to no mathematics at all (McAlinden & Noyes, 2019a) if students cannot access, or are reluctant to take, A-level Mathematics.

Core Maths is proposed, therefore, as part of a study programme, much as mathematics is widely included in upper secondary programmes in other developed countries (Hodgen et al., 2010; Smith & Morgan, 2016). England's challenge is that, from a low mathematics participation base, the post-16 system needs a way of marketing these qualifications, according to qualities valued by institutions and students. One strategy is to emphasise their potential to complement and support a range of academic and technical programmes, including those with specifically embedded mathematical and/or quantitative elements (McAlinden & Noyes, 2019a; Smith, 2017). It is important to note the assertion within technical and policy documentation (e.g. Department for Education, 2013) that one of the purposes of Core Maths is to support *further* study, rather than study contemporaneous with the Core Maths course itself, a fine but perhaps salient distinction:

> It is essential that Core Maths qualifications help prepare students for higher education and employment. (Department for Education, 2013, p. 9)

This shift in emphasis amongst school and college communities, towards emphasising the more immediate benefits of Core Maths rather than benefits which will be realised in the future, is central to the argument of this paper.

Aim of this paper

In England, the policy aspiration is to encourage many more students to study mathematics within their post-16 programme, in line with upper secondary students across the developed world. The challenge is to develop provision from a very low base.

One recruitment strategy, which we encountered during a study investigating the first few years of implementation of Core Maths (Homer, Mathieson, Banner, & Tasara, 2020), is to present Core Maths as benefiting other curriculum subjects. A senior leader in one of our case study institutions posed a pertinent question:

> You might argue [that] just doing it [Core Maths] helps the main programme benefit … Some of that, you'd never fully know. Do they get better grades on the main programme because they've done Core Maths? (Vice Principal, Dickenstein SFC)

Accordingly, this paper seeks evidence, from a range of data, that these new qualifications might support other subjects included in students' main programmes.

Data and methodology

This paper draws on qualitative and quantitative data from a wider study (Homer et al., 2020). We analyse three types of data: interviews with teachers, managers and students between autumn 2017 and summer 2019; online survey responses from mathematics teachers and mathematics education professional bodies in summer 2019; and national student qualification data from 2018. Our methodological approaches to these data are outlined below.

Interview data with students and teachers

Qualitative data was gathered from thirteen post-16 centres in England (Table 1), during three rounds of fieldwork, in autumn 2017, summer 2018 and summer 2019. Pseudonyms are allocated to these centres, using names of recent presidents and vice presidents of the International Mathematical Union. The part of each institution's name indicating its type (Sixth Form College, Comprehensive School etc.) is retained.

Semi-structured interviews were conducted with 23 Core Maths teachers, 16 senior leaders (Principals, Headteachers, Deputy Headteachers, Heads of Faculty, Heads of Sixth Form), and 14 Heads of Mathematics/Curriculum Leaders for Mathematics. Across three visits, 121 students in total were also interviewed. Most were studying Core Maths at the time; some had completed the course the previous year. Interview questions to staff centred around mathematics education and its place in the post-16 curriculum, both within each institution and more broadly across the education system. Students were asked questions relating to their study programmes, their aspirations, their experiences of school mathematics – prior to and now within Core Maths – and their reasons for taking Core Maths. In both cases, the semi-structured nature of the interviews meant that particular questions could be asked across the sample, but also allowed participants to introduce into the conversation issues or factors which were important or particular to them and their circumstances.

Interviews were transcribed, and coded inductively using the software package NVivo 11. Separate codeframes were created for students and for staff, though there were commonalities. The first codeframes were developed at the second and third data analysis points, with new codes added and marked as such. For example, at the second point, we coded *Changes in Core Maths delivery* which had occurred since the first visit.

Staff data were organised into eleven primary-level codes, covering themes such as *Curriculum offer* and *Core Maths marketing*; each was subdivided, then mostly subdivided again, into more detailed and specific subcodes. Similarly, student data produced five primary codes (*Future plans*, *Previous experiences of mathematics*, *Reasons for doing Core Maths*, *Study programme*, *Core Maths itself*), themselves subdivided.

A theme emerging from staff and student data analysis was *Core Maths supporting other subjects*. For students, this theme permeated *Reasons for doing Core Maths*, *Core*

Table 1. Participating institutions (pseudonyms) and type, geographical location, awarding body, course length.

Case study	Institution type	Region of England	Core Maths specification[1]	Course length (years)
Ball Comprehensive School	11–18 schools	North East	AQA	2
Bismut Academy		East Midlands	OCR	1
Donaldson High School		West Midlands	AQA	2
Lions Academy		East Midlands	OCR	1
Mumford High School		Yorkshire and Humberside	OCR	2
Palis High School		London and the South East	Edexcel	2
Coates Studio	14–19 studio school	North West	AQA	1
Rousseau UTC	14–19 UTC	West Midlands	AQA	2
Arnold College	General FE colleges	West Midlands	AQA	1
Jones College		North West	AQA	1 and 2
Dickenstein SFC	Sixth Form Colleges (16-19)	Yorkshire and Humberside	OCR	1
Mori SFC		North East	Edexcel	1
Viana SFC		North West	AQA	2

Maths itself, *Future plans* and *Study programme*. In staff data, the theme crossed most primary codes, including *Curriculum offer*, *Data/accountability*, *Core Maths marketing*, *Staff*, *Policy*. These data have informed the current paper.

Online survey data

In summer 2019, an online survey of Level 3 providers, and other stakeholders within post-16 mathematics education in England, investigated the extent to which our case study findings were more broadly relevant. The survey asked a range of questions around local implementation of Core Maths, and reasons for offering Core Maths, and consisted mainly of closed responses (Homer et al., 2020). A number of open-ended questions on key issues allowed narrative responses. The survey, made live in May 2019, closed in August 2019 with 164 responses, mainly from Core Maths teachers, with a small number of responses from awarding body representatives and other stakeholders. The responses were broadly representative by institution type (e.g. FE college, Sixth Form College, school sixth form), and also geographically (Homer et al., 2020).

Methods of statistical analysis for the questionnaire data are mostly descriptive in nature. Open responses provide illustrations of archetypal views from the data. The survey results were broadly in line with those from the other data sources, and here we draw on survey findings for illustration where appropriate to the argument of this paper.

National qualification data for England

From the National Pupil Database (Department for Education, 2020), all students in England awarded a Core Maths qualification in 2018 ($n = 6561$), the most recent year for which data was available, are identified. Since Core Maths is studied alongside a range of other subjects, we then identify what other qualifications these students were awarded in 2018, and which qualifications had the highest number of entries. For this list of qualifications, we can compare typical outcomes, between those who had studied Core Maths and those who had not.

Table 2 shows the sample sizes of the five qualifications (all A-levels) with the highest entry numbers amongst Core Maths students in 2018, and the sample sizes for students awarded the same qualification in 2018 but who were not awarded Core Maths. Because Core Maths can be taught over one or two years, we also include Core Maths qualifications awarded prior to 2018.

We note that the proportion of students awarded Core Maths is small (around 2–3%) in all five qualifications.

Table 2. Sample sizes for attainment comparison (NPD).

Qualifications with highest number of entries for Core Maths students (2018)	Had a Core Maths qualification? No	Yes	% With Core Maths	Total in cohort
Psychology A-level	43,844	936	2.1%	44,780
Biology A-level	25,591	800	3.0%	26,391
Business Studies A-level	20,760	632	3.0%	21,392
Geography A-level	20,869	551	2.6%	21,420
Chemistry A-level	12,212	446	3.5%	12,658

For each subject listed in Table 2, we compare the A-level attainment of students who had studied Core Maths, and those who had not. We utilise the NPD scoring system of A* = 60, A = 50, B = 40, C = 30, D = 20, E = 10, U and X = 0, so that successive grades differ by 10 points.

We first perform this comparison in a "raw" analysis, ignoring differences such as gender profile or prior attainment in mathematics between the two groups. This is essentially an independent sample t-test comparing the two groups, but with a focus on effect size, as measured by Cohen's *d*, rather than on *p*-values (Wasserstein & Lazar, 2016).

A second, more complex analysis presents the outcome of a statistical modelling exercise, a random intercept, variance component multi-level model using the linear mixed model procedure in SPSS (Field, 2013, ch. 20). It compares the two groups but controls for a range of additional factors: prior attainment in GCSE English and Mathematics; gender; institution type; and three measures of socio-economic status: eligible for free schools meals, "Disadvantaged" at the student level prior to age 16 (both Department for Education categorisations), and "Disadvantaged" aggregated to the institution level. Other potential co-variates (e.g. ethnicity) were not used, since there was too much missing data by design: in England, some student-level characteristics are not collected in all types of institution, for example, further education colleges. This is an important limitation of this analysis: co-variates such as ethnicity cannot be included and, in the technical statistical terminology, are missing not at random (Buuren, 2012, chap. 1). Our key predictor of interest is whether or not students had studied Core Maths (1 = Yes, 0 = No).

Before making any comparisons between the two groups, students are removed from the analysis if they have at any time also been awarded an AS/A-level in mathematical subjects such as Mathematics, Further Mathematics or Statistics, which could potentially have affected students' examination outcomes in these other subjects. This allows us to obtain a more well-defined estimate of a Core Maths effect on student outcomes.

Findings

The support Core Maths is perceived to offer other curriculum subjects permeates the case study and questionnaire data. If this justification is to be used successfully to expand take-up of the qualification, we should consider whether it is supported by any additional evidence. This question is also relevant to jurisdictions where mathematics is generally included within broader study programmes.

This section presents findings derived from consideration of the three complementary data sources detailed above. First, we illustrate staff and student perspectives, mainly from our case studies and also supported by the online survey. Subsequently, we present analysis of national quantitative data to estimate the impact of studying Core Maths on student outcomes in other subjects.

Perceptions of Core Maths supporting other subjects

Teachers' generally positive perceptions

Teachers and managers across our case study institutions believe that Core Maths supports the mathematical or quantitative aspects of other curriculum subjects. Ball's Head of Mathematics says that:

> anyone who's doing a science, [and] not doing A-level Maths … if you're doing that kind of subject, you should be keeping your maths going …

She teaches statistics in Core Maths, which links to other subjects:

> I'll do the regression lines and that again, which will come up in other A-levels.

At Dickenstein, teachers explicitly considered which subjects Core Maths might support:

> The stats is more open to link to other subjects like Psychology, science, Biology, Geography, Business … Even in Sociology and things like that they are going to see, even just statistical charts, and be able to interpret them as well. (Core Maths teacher, Dickenstein SFC)

Online survey responses strengthen this finding. Asked why their institutions offered Core Maths, the most popular response (76.9% of respondents reporting this as a reason) was that it supports Level 3 science subjects. The second most popular (68.5% selecting this) was that it supports Level 3 non-science subjects. One surveyed teacher added:

> It's a brilliant course which has really motivated some students regarding their maths in other subjects.

This representative quote reflects the importance of the affective relationship with mathematics, rather than a particularly important piece of content or skill.

Using this perception to market Core Maths

Belief in the benefits of Core Maths is translated into a strategy to promote it. Core Maths teachers at Lions and in the other case study institutions actively talk to students and present at open evenings about the links between Core Maths and other subjects they may be doing now or at university. The online survey response below, from a mathematics teacher, reflects the widespread perceived need to promote Core Maths's benefits to other curriculum areas:

> We have promoted Core Maths at open evenings, but have now appreciated that we need advocates in other subject departments to sing its praises. Accordingly, I recruited student volunteers to base themselves in those departments with accompanying literature to evangelise about core maths and its impact on success in other A level subjects.

Dickenstein strongly advises Applied Science students to take Core Maths:

> We decided we were going to recommend it to people on Applied Science, as a trial, and, we thought that would help with the stats. But [teacher] did a bit of a survey of staff when the new A-levels were coming in, as to how much extra maths content there was, and he had a long discussion with Psychology about the extra stats content, and how they thought it would support that really well. (Head of Mathematics, Dickenstein)

We found Core Maths being recommended to students taking Psychology, Biology, Business, Geography, Chemistry, IT, and Applied Science, as A-levels, BTECs,[2] and Cambridge Technicals. As the title of this paper shows, students were commonly persuaded that mathematics would help them with numerical/quantitative elements in their other subjects:

> It was advertised to us, it goes well with these subjects, and that's what got me on board … (Core Maths student, Ball)

Some centres systematically align Core Maths with particular subjects or pathways, to ensure a pipeline of Core Maths recruits. Jones FEC and Coates Studio offer Core Maths within the TechBacc[3] on IT/scripting and programming pathways. Viana SFC's deliberate strategy is to promote Core Maths as a support course for other curriculum areas; the Head of Mathematics says it is the only viable way of maintaining the course.

Students' generally positive perceptions

The positive comments from students beginning their Core Maths course commonly reflect the marketing strategy which recruited them. We tracked some of those students, revisiting them at the end of the academic year. Mumford student Lucy told us both times (without being reminded, on the second occasion, of her earlier comments) why she enrolled on Core Maths:

> So, they're [Biology, Chemistry and Psychology] obviously, quite maths-based, and I don't want to do A-level Maths, so I thought this would help me develop my maths for those other subjects … (Lucy, visit 1)

> I thought that it would help with my other subjects, because I'm doing Biology, Chemistry and Psychology. So, the statistics part is obviously useful in those subjects … (Lucy, visit 2)

Lucy's first quote shows commitment to a general continuation of mathematics, linked to her study programme. The second highlights a specific aspect of Core Maths which she considers helpful.

In fact, in the summer terms of 2018 and 2019, students who were halfway through or completing their Core Maths course were generally positive about Core Maths supporting them in a range of subjects:

> … it's helped. Yeah, a lot, in the maths part [of Applied Science]. (Core Maths student, Dickenstein)

> … it helps with my other subjects. I do Physics, so, it's a lot of maths … it's a lot of calculations, isn't it? It's just a lot of formulas and stuff. (Core Maths student 1, Coates)

One Mumford student said that doing Core Maths alongside Economics, when many classmates were taking A-level Mathematics, had helped her "keep on a level with [mathematics]". Some also said they appreciated exploring subject-related mathematics in Core Maths lessons more deeply than was possible in their other subject lessons:

> It's good to practise maths, cause we've got a maths part of Computing coming up, so, it's good to go over it. (Core Maths student 2, Coates)

At Viana, students approaching the end of their two-year Core Maths course say they feel they have not had sufficient time to focus on the quantitative aspects of Psychology within Psychology lessons, and that covering those aspects in Core Maths has been helpful. They are also glad to have had time and opportunity to learn to use a scientific calculator properly, and to practise drawing graphs – skills required in their other subjects.

Connections between Core Maths and BTEC Applied Science were mentioned in several case studies. Students taking Core Maths in the second year of Applied Science described how the science fed into Core Maths. Teachers at Lions and Mumford corroborated that their students recognised connections between Core Maths and other subjects. Here we note, not just mathematics supporting other curriculum areas, but a bidirectional influence.

Some students went further, displaying a mature and perceptive appreciation of Core Maths's wider benefits:

> The thing with maths is, it helps you with everything cause it's a mode of thinking, like, you just break things down and add them up together, reconstructing it, it can be applied to any sort of thing … (Core Maths student, Arnold)

The overwhelmingly positive perceptions of students and teachers acknowledge relationships between mathematics and other quantitative subjects. They also recognise the wider relevance of Core Maths, the opportunity to develop mathematical thinking, and reinforcing in one context concepts learned elsewhere.

Dissenting and disappointed voices

We found relatively little student data expressing a perceived lack of connection between Core Maths and other subjects, although we know that some students with negative experiences left the course before we could re-interview them. Where these views did exist, they tended to come from students who were, in their words, "forced" to enrol on Core Maths, a situation encountered at Jones and Viana in particular. Some students accepted that they were enrolled onto mathematics for their own benefit, and some could see wider benefits of taking Core Maths. However, Jones and Viana included students who were found to be generally less positive than students who had more choice in taking Core Maths; some fairly strong comments were heard from students in these two case studies, such as "I hate it. I shouldn't be here".

Students in this group were those most likely to say they saw no link between Core Maths and a supposedly related subject. Our data suggest that, in such cases, student expectations were possibly raised by teachers persuading them to take Core Maths on the premise that it would benefit their other subjects, a prediction which students subsequently decided did not live up to its promise.

Such views came mainly from Viana students, where college policy was to enrol students on Core Maths who wished to enrol on courses but did not quite meet the GCSE Mathematics access grade. A-level Biology students, obliged to enrol on Core Maths due to not meeting the GCSE Mathematics access grade for acceptance onto Biology, denied they had found any of Core Maths relevant to Biology. Some Year 12 Viana students on a two-year Core Maths course wondered when Fermi estimations would come into their other subjects, because they had seen no connection so far. Others, enrolled onto Core Maths to support Sociology, demonstrated particular dissatisfaction and negativity.

Biology, of all the sciences, is perceived as the least supported by Core Maths, by Viana students, more generally negative because of their manner of enrolment onto the Core Maths course, but also across the case studies. This is an interesting finding, given that, during the development of Core Maths qualifications, Biology was seen as being well served mathematically by Core Maths (Browne et al., 2013).

Some Rousseau vocational engineering students said they felt Core Maths did not support their engineering course. They felt Core Maths was an additional rather than a complementary course, precisely because they were covering the requisite and relevant mathematics in engineering lessons; Core Maths was a completely different kind of mathematics. They did, however, recognise that Core Maths could be helpful in other respects, such as personal finance contexts.

Amongst teachers, the strongest dissenting voices were in the online survey, and generally referenced disappointment at what they thought Core Maths should offer in supporting other subjects. One teacher's institution had been offering the AQA specification[4] with the Graphical Techniques option:

> Terrible course, does not support many other subjects as hoped … I think Core Maths needs to be reconsidered. We sold it as supporting many other subjects but the compulsory part doesn't really do this …

Another teacher reflects, below, on the consequences of pursuing a marketing strategy advertising benefits which prove undeliverable:

> The first time we ran it as a 2-year course specifically for [A-level] Chemists, when it had been mis-sold as having subject-specific content. Several lost interest.

Both teachers believe Core Maths was meant to support other Level 3 qualifications directly. Their disappointments led to one of the centres withdrawing Core Maths altogether, the other deciding to change the optional paper to statistics which was considered more relevant to more students' other subjects.

Summary of qualitative evidence

The belief that Core Maths does, or should, support other curriculum subjects is felt strongly across the case studies, independently of whether students opt in or are enrolled quasi-automatically in conjunction with other courses. Student data show this assertion being commonly used to market the qualification to them. On experiencing the course, students reported on the whole that they felt Core Maths had usefully supported other subjects. Those who felt they had not experienced this connection tended to have been enrolled reluctantly, though this was not exclusively the case.

Core Maths student outcomes in other subjects

We now examine national data for the qualifications most often taken by Core Maths students, asking whether this widespread perception is reflective of Core Maths students' wider assessment outcomes.

Comparison of raw attainment in five qualifications

First, we present a raw comparison of attainment for the five qualifications shown in Table 2 above. Recall that a grade C is worth 30 points, and 10 points separate successive grades, in the NPD scoring system used. Table 3 compares the mean attainment, in each of the five subjects, of students who had, and had not, taken Core Maths.

Table 3. Comparison of raw attainment in five qualifications (NPD, 2018).

Qualification	Had a Core Maths qualification?	N	Mean points	Std. deviation	Std. error mean	CI lower	CI upper	Difference as % of grade = 100 × points difference/10	*p*-Value	Cohen's d
Psychology	No	43844	31.90	13.67	0.065	31.77	32.03			
	Yes	936	31.44	12.49	0.408	30.63	32.26	−4.6	0.308	0.02
Biology	No	25591	28.52	14.50	0.091	28.34	28.70			
	Yes	800	26.90	13.86	0.490	25.92	27.88	−16.2	0.002	0.08
Business Studies	No	20760	31.94	12.61	0.087	31.77	32.12			
	Yes	632	30.65	12.64	0.503	29.64	31.65	−12.9	0.011	0.07
Geography	No	20869	34.84	12.82	0.089	34.66	35.01			
	Yes	551	33.03	12.11	0.516	32.00	34.06	−18.0	0.001	0.10
Chemistry	No	12212	27.41	14.56	0.132	27.14	27.67			
	Yes	446	25.11	13.86	0.657	23.80	26.43	−22.9	0.001	0.11

Data source: NPD, 2018.

Table 3 reveals that Core Maths students have lower average attainment across all five qualifications (see *Mean points*). The differences are around 5% of a grade lower in Psychology to 23% of a grade lower in Chemistry. According to standard terminology for describing effect sizes, these differences are "small" (Cohen, 1988), although all differences bar for Psychology are statistically significant at the 5% level.

Multi-level modelling of attainment outcomes controlling for other factors

Table 4 summarises the key parameter of interest in each of five multi-level models which compare attainment between the two groups – whether or not students had also studied Core Maths (1 = Yes, 0 = No) – but now controlling for prior attainment in GCSE English and Mathematics, gender, institution type, and three measures of socio-economic status.

All the estimates of the "adjusted" Core Maths effect on attainment are quite small: at most, the effect size is 13% of a grade for Business Studies, the only statistically significant result in these analyses, and very similar in size comparing the raw estimate (−12.9%, Table 3) with the adjusted (−12.8%, Table 4). This latter estimate would indicate a small negative average effect of studying Core Maths on A-level outcomes for this qualification, once controlling for other factors.

Direct comparison between the other four estimates in Tables 3 and 4 shows that the Core Maths "effect" on outcomes moves from negative in the raw analysis (Table 3) to positive for Psychology and Biology (Table 4). For Geography and Chemistry, the adjusted estimates in Table 4 are closer to zero than in Table 3, but remain slightly negative. However, none of these four estimates is statistically different from zero in the adjusted (multi-level) model.

It is important to acknowledge the limited and problematic nature of this analysis. Other factors that we could not include (e.g. student ethnicity, unidentified institutional factors, more fine-grained measures of socio-economic status, more comprehensive measures of prior attainment than can be included here, possible effects of differential access requirements for courses which depend on GCSE Mathematics outcomes) may come into play. Additionally, missing data is, to a degree, problematic: around 10% of the predictors used in modelling included missing data, some definitely missing not at random, possibly introducing further bias into the estimates presented in Table 4.

Despite these methodological challenges, this analysis is best interpreted as indicating that any causal Core Maths effect on A-level outcomes for each of these five subjects is likely to be quite small at the aggregate level nationally. More research is needed in this area.

Table 4. Core Maths coefficient in multi-level model comparing A-level attainment (NPD, 2018).

	Core Maths estimate							
A-level subject	Points	% of grade	95% Confidence interval for points		Std. error	df	*t*	*p*-Value
Psychology	0.17	1.7	−0.64	0.99	0.42	35197	−0.42	0.68
Biology	0.37	3.7	−0.58	1.31	0.48	16369	−0.76	0.45
Business Studies	−1.28	−12.8	−2.27	−0.29	0.50	15605	2.54	0.01
Geography	−0.46	−4.6	−1.46	0.55	0.51	14821	0.89	0.37
Chemistry	−0.04	−0.4	−1.38	1.30	0.68	7724	0.06	0.95

Data source: NPD, 2018.

Discussion

Technical and policy documentation around Core Maths (e.g. Department for Education, 2013) explicitly states that one of the purposes of the new qualifications is to prepare students for *future* contexts of work, study and life. However, our data reveal a widespread perception, amongst staff and, to a slightly lesser extent, students, that studying Core Maths *contemporaneously* supports a range of other post-16 courses. This belief is commonly translated into a means of marketing Core Maths to students as they enrol onto post-16 programmes.

Data from students halfway through, or completing, their Core Maths course show that, in most cases, Core Maths is still seen as supporting the quantitative or mathematical aspects of subjects such as Geography, Applied Science and Psychology. This mirrors the widely-held view that students of quantitative subjects across the curriculum benefit from developing mathematical understanding, and problem-solving and analytical skills, for use in different contexts (British Academy, 2015; Geiger et al., 2015; Quinnell et al., 2013; Smith, 2017).

We set out in this paper to explore whether our data showed any evidence that studying Core Maths was beneficial to students' outcomes in qualifications studied contemporaneously. Analysis of national data highlights two main findings.

First, although there is a widespread perception, in centres offering Core Maths, that the course will benefit students in their other quantitative subjects, this perception is not prevalent or sufficiently powerful amongst the wider, national, school and college population for schools and colleges to be, en masse, harnessing the potential of Core Maths. National data indicate that, after removing from the analysis students taking Level 3 mathematical qualifications like A-level Mathematics, only a small percentage of the remaining students, ranging from 2.1% to 3.5% for the five most popular Level 3 courses, currently take Core Maths alongside other subjects.

According to policy documentation, Core Maths can be incorporated into the study programme of any post-16 student who has attained grade 4+ in GCSE Mathematics (Department for Education, 2018). The documentation does not suggest Core Maths should be directed at particular students. It contains an explicit acknowledgment that skills and knowledge developed through Core Maths can be deployed later in a wide variety of contexts, including day-to-day life. The Core Maths initiative reflects a government ambition to encourage the study of mathematics to 18 for the majority of, if not all, students, suggesting that the opportunity should not be prioritised for those studying particular other subjects at Level 3, and that the benefits of studying mathematics beyond GCSE reach beyond supporting other subjects.

Second, we found no evidence of a beneficial effect of studying Core Maths on attainment in other subjects, in strong contrast to the general perception amongst our participants. Our quantitative analysis points to a small statistically significant negative effect in one case (Business Studies), and to non-significant effects elsewhere. Despite caveats related to this analysis, it seems likely that studying Core Maths alongside these A-level subjects has made little or no difference, at the national level, to the relevant examination outcomes.

In part, a parsimonious explanation might be that these qualifications are not assessing in any sustained manner those skills developed during the study of Core Maths. In asking whether examination outcomes should be expected to be directly affected by studying Core Maths, we should highlight that a relatively small proportion (variously 10% or 20% according to the subject) of the summative assessment in each of the five most popular A-level qualifications taken by Core Maths students is explicitly mathematical in nature (Department for Education, 2014). In addition, the various Core Maths specifications and their optional papers cannot realistically hope to provide specific mathematical content and applications to support all students doing all other subjects.

Our case study and online survey data suggest that the way in which Core Maths is implemented in different institutions also varies greatly (Mathieson, Homer, Tasara, & Banner, 2020), being aligned, or not aligned, in very different ways with students' main programmes and/or other subjects. Our modelling produces an averaged national Core Maths effect, potentially missing nuances in what might be happening in individual institutions or with particular students or groups. Expectations of finding a clear positive Core Maths effect in examination grades might therefore be unrealistic.

These findings seem to tell a different story from the small but statistically significant effect of the Extended Project Qualification (EPQ). Like Core Maths, the EPQ is normally completed alongside other post-16 courses as an extension of the typical university entry requirement of three A-levels (or equivalent). Since the EPQ involves designing and undertaking a project independently, it is thought to enhance study skills including self-motivation, perseverance, and independent learning, and has been welcomed by HE as good preparation for undergraduate study (Ofqual, 2018; Russell Group, 2020). Students taking EPQ have been found to achieve, on average, better results across their A-levels than their peers (Gill, 2018): the impact of taking the EPQ was found to be of the order of a single A-level grade for a student taking four A-levels.

Dickenstein's Vice Principal, quoted earlier, asked a pertinent question:

> Do [students] get better grades on the main programme because they've done Core Maths?

Whilst we found no evidence of a direct aggregate benefit when comparing grade outcomes, it is possible that studying Core Maths does support students with other subjects in ways that are not overtly captured by focusing on examination outcomes. A Geography teacher at one of our case study institutions provided an insight into what she felt was especially beneficial about Core Maths. She believed it gave her students confidence, which is "the main thing". Referring to students' mathematics skills, she used the phrase "use it or lose it": she was pleased that her Geography students could practise statistics and graph skills within Core Maths.

Our evidence suggests that it may be counterproductive to overplay the attainment link between Core Maths and other subjects, since this may result in unrealistic expectations of both staff and students. We saw earlier the disappointment of the online survey respondents reporting that Core Maths had been "mis-sold", and the confusion of the students who could not fathom where they might use Fermi estimation in their other subjects.

Ultimately, a more holistic message to institutions and students about the continuous study of mathematics, and a broader, further-reaching application of skills and knowledge, could be most useful for the growth of Core Maths participation. Mathematics might be included in the curriculum, as it is in other developed countries, for a whole gamut of reasons (Skolverket, 2011; Smith & Morgan, 2016). It is as much an important part of our historical and cultural heritage, an aid to thinking creatively outside the mathematics classroom, and part of developing citizens who contribute to the state and to society, as it is a practical aid to examination success in other curriculum areas or preparation for work and higher education. Confident numeracy in adulthood for all would, in and of itself, be an admirable goal.

Notes

1. Advanced Level and Advanced Subsidiary level. A-levels are longstanding academic qualifications taken by post-16 students in England; the AS can be gained by undergoing assessments at the end of the first year of the two-year A-level course.
2. Business and Technology Education Council. Career-based qualifications in vocational subjects.
3. The Technical Baccalaureate, a Level 3 performance measure which includes three technical qualifications, a maths qualification, and the Extended Project Qualification.
4. AQA's specification has one compulsory paper, and three optional papers from which one is chosen. See https://www.aqa.org.uk/subjects/mathematics/aqa-certificate/mathematical-studies-1350 (accessed 16th April 2020).

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