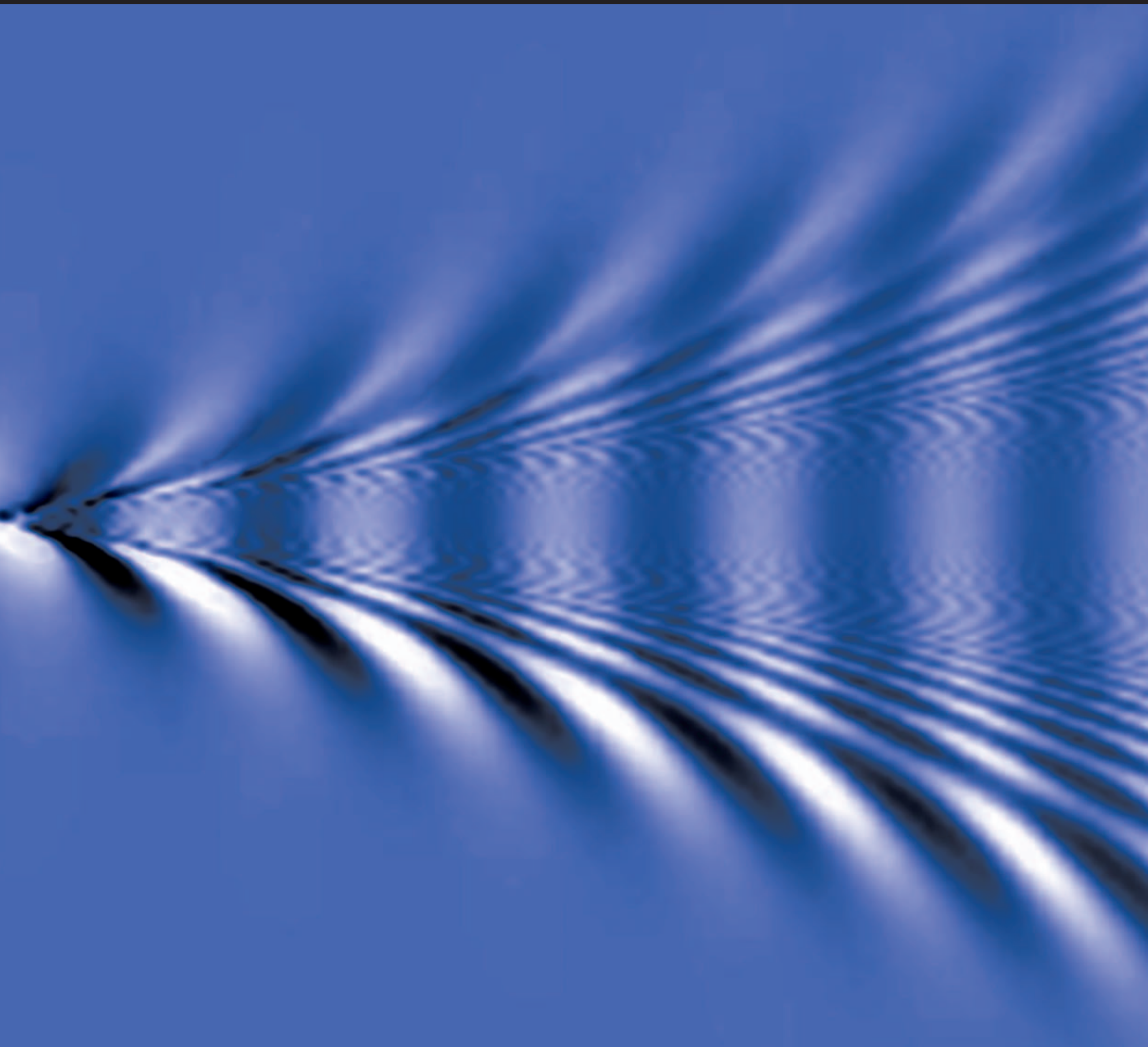
An Institute of Physics report | **July 2011**

Mind the Gap

Mathematics and the transition from A-levels to physics and engineering degrees

A report prepared for the Institute of Physics by EdComs



IOP Institute of Physics

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Contents

1: Executive summary

The Institute of Physics commissioned EdComs to investigate anecdotal evidence that physics and mathematics A-levels are not preparing students sufficiently for undergraduate physics and engineering courses, and that the physics and mathematics A-levels are not providing enough encouragement for students to take up undergraduate physics courses.

A mixed-method approach was taken to meet the research objectives, consisting of six telephone interviews with physics and engineering academics; an online survey with 393 physics, engineering and computer science students; case-study visits at three universities involving face-to-face interviews with 24 physics and engineering students and nine mathematics students; and an online survey with 40 academics from UK universities.

1.1. Summarised findings

1.1.1. Expectations of their degree course

Just over half of the students surveyed (54%) felt that the expectations of their degree course had been met, and 47% felt that the mathematical content specifically had met their expectations. Nearly four-fifths (79%) felt that they were able to deal either very well or quite well with the mathematical content of their course, though 55% of academics felt that students were not very/not at all well prepared to cope with this content.

1.1.2. Reactions to specific mathematical content

Students and academics responded in similar ways when asked what elements of the mathematical content students found particularly easy or difficult. Algebra, differentiation and logs were highlighted by both cohorts as being relatively easy; while integration, identifying particular equations and techniques to deal with problems, and vectors and scalars were reported by both samples to be more of a struggle.

1.1.3. Support offered

The vast majority (92%) of academics said that their department/school offered some form of support to students to help them deal with the mathematical content of their degree. Slightly fewer (83%) of students indicated that they had been offered any additional support (although 11% said that they didn't know if this was on offer). Students felt that the most useful form of support for them was extra question sheets to practise problem solving (35%), and "self-help" options in general were seen to be most useful among students than face-to-face support (52% vs 31%). Four-fifths (80%) of those students that had taken advantage of any form of support felt that this had addressed their issue, although only 41% of academics felt that the support they were offering was sufficient.

1.1.4. Long-term impacts

A large proportion (92%) of academics felt that a lack of fluency in mathematics was an obstacle to students achieving their full potential in the long term, and more than four in five (85%) agreed that a lack of fluency affected their department's ability to deliver an optimal programme of study.

1.2. Conclusions

Some of the key concluding themes emerging from the research were around the following:

1.2.1. Further mathematics

Those students who had studied further mathematics to A- or AS-level standard reported coping better with the mathematical content of the degree, and as such perceived that they required less additional support throughout their studies. Many students and academics felt that studying further mathematics should therefore be made a requirement of studying physics or engineering at university.

1.2.2. Changes to A-level mathematics and physics structure

It was felt by academics that in an ideal scenario, changes should be made to the A-level structure – both the way in which mathematics is taught at that level (it was felt that it is taught too much to exam rather than to promote contextual understanding of the topic), and also to the amount of crossover between mathematics and physics at A-level (the two subjects are currently perceived by students to be quite separate). Students also felt that the approach of teaching them mathematics to exam at A-level did not give them robust knowledge of the background to what they were learning, and as such did not equip them to apply their learning to physics.

1.2.3. Practice

Further to this, many students and academics felt that a more achievable way of tackling the perceived lack of fluency would be to ensure that students are able to practise their mathematics more. Academics felt that this should be encouraged at A-level as well as at university, via problem sheets and tutorials. An issue with this was that many students felt that they were too time-poor for this to be viable, and academics said that while making this compulsory could be beneficial to the students, they feared that enforcing this could put unsustainable strain on resources in their departments in the long term.

1.2.4. Reasons for not studying physics

Many mathematics students reported being unaware that physics contained so much mathematics, and that a love of problem solving, which was felt to be absent from physics degree courses, was what had pushed them towards pursuing mathematics to degree level. Students felt that the mathematical nature of degree-level physics should be made clearer, so that a more informed choice could be made.

There was also felt to be a lack of knowledge around what a physics degree could lead into, career-wise. Many of the mathematics students interviewed felt that mathematics gave them broader options post-graduation.

2: Background

The Institute of Physics (IOP) had anecdotal evidence that physics and mathematics A-levels are not preparing students sufficiently for undergraduate physics and engineering courses. A number of academics reported that university physics and engineering departments have to spend more time coaching their first-year students to become proficient (or "fluent") in mathematics before they are able to move onto the main course material. The IOP, along with the Engineering Professors' Council, wished to investigate this further and understand what could be done to better prepare students for their undergraduate physics and engineering courses.

There was also a feeling within the IOP that mathematics and physics A-levels are not providing enough encouragement for students to take up undergraduate physics courses. Undergraduate physics courses are more mathematical than physics A-level courses, but students may not be aware of this based on the content of physics A-levels. There was a question around the extent to which this lack of information could discourage students who are motivated by solving mathematical problems from reading physics.

3: Research objectives

The IOP therefore had the following objectives for the research:

1. To understand the extent to which students are prepared to deal with the mathematics aspects of physics and engineering undergraduate courses.

- What experiences do students have of the transition to physics or engineering degree courses and how well prepared are they?
- How do students react to the mathematical elements of their physics and engineering courses?
- What aspects of mathematics within physics and engineering courses do students find most challenging?
- What gaps do students think there are in their preparation for physics or engineering degree courses?

2. To understand students' (who have relevant qualifications to take a physics course at university but choose not to) perceptions for and against taking an undergraduate physics course.

4: Methodology

A mixed-method, four-stage approach was taken to meet the research objectives. The methodology is summarised below; full details of the approach, including more detailed sample breakdown, can be found in the appendix[1].

4.1. Stage one: qualitative telephone interviews with academics

Six 45-minute one-on-one telephone interviews were conducted with academics from three Russell Group universities (one physics academic and one engineering academic from each university).

These interviews were conducted 14–24 February 2011.

4.2. Stage two: quantitative survey with physics and engineering students

A total of 393 first- and second-year students, from the same three Russell Group universities, were surveyed through a 10-minute online questionnaire. They were contacted via the contacts provided by IOP (an e-mail, drafted by EdComs and IOP and containing a link to the survey, was forwarded to students from an academic at their university).

The survey ran 28 February – 11 March 2011. A copy of the questionnaire can be found in the appendix[1].

4.3. Stage three (i): case-study visits with physics and engineering students

Qualitative face-to-face interviews were then conducted with 24 first- and second-year physics and engineering students from the same three universities that had taken part in the previous phases of the research. Respondents to the online survey had been asked to indicate whether they would be happy to take part in a further phase of research, and those who consented were re-contacted using the contact details that they had supplied. Respondents to be included in this phase were selected in order to provide a mix of degree course, year of study, whether they had taken further mathematics at A- or AS-level, and gender. Many had not decided whether to pursue a Bachelors or Integrated Masters qualification, so that information has not been noted in this sample breakdown.

An EdComs moderator visited each university to conduct student interviews. It was necessary to fit in with student timetables, so interviews ranged from being one-on-one to being conducted in a focus-group setting. As a result the interviews ranged from 30 to 60 minutes in length, depending on the number of students being interviewed.

These interviews took place 23–29 March 2011.

4.4. Stage three (ii): case-study visits with mathematics students

During the three case-study visits, nine first-year mathematics students from the same universities were also interviewed in relation to the secondary objective of the research. These students were chosen to have had the relevant qualifications to study physics at university (mathematics and physics A-level), and were recruited to take part via academics at those universities.

4.5. Stage four: academic survey

Finally, a 10-minute online quantitative survey was conducted with 40 academics (34 physics academics and six engineering academics) from physics and engineering departments in 33 UK universities. A link was sent to a contact at each department by the IOP/Engineering Professors' Council.

This survey ran 4 March – 12 April 2011. A copy of the questionnaire can be found in the appendix[1].

4.6. Analysis and reporting

Qualitative data was gathered into a thematic template to ensure coherence across the research team, and was further evaluated during internal analysis sessions.

Quantitative student data was analysed across the following criteria:

- Degree course;
- Year of study;
- Whether further mathematics was studied;
- Mathematics module studied (mechanics vs statistics);
- Grade achieved at A-level mathematics;
- Whether additional support was taken up;
- Type of secondary school attended.

Only significant differences at a 95% confidence level have been commented on. Due to the small sample size, academic quantitative data was analysed only at an overall level. Direct quotes taken from qualitative interviews have been specified as

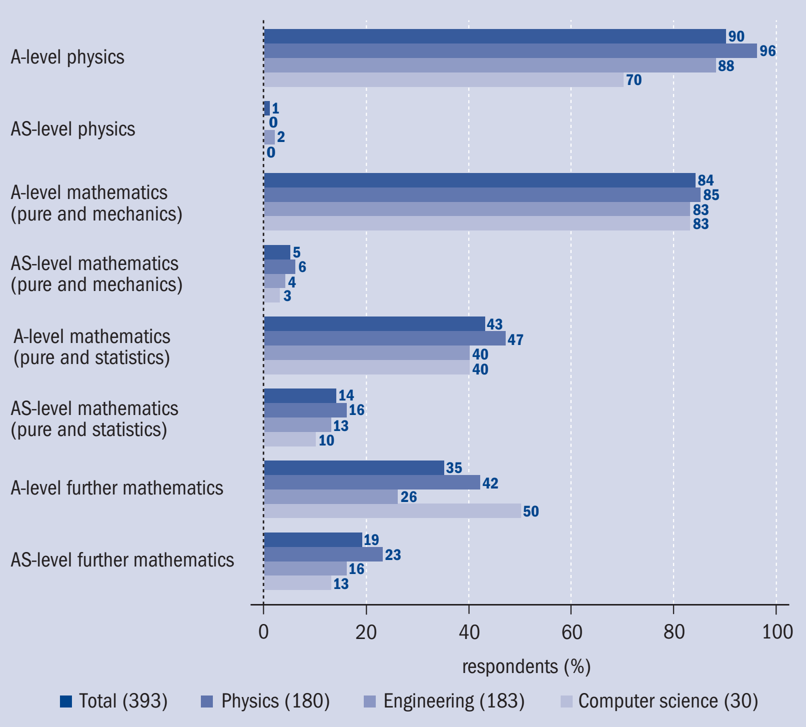
[1] For a copy of the appendix please contact sophie.robinson@iop.org.

"physics academic" or "engineering academic". Quotes taken from open-ended questions asked in the online academic survey cannot be attributed to individual respondents and as such are labelled only as "academic".

The sample is not representative of the student or academic population as a whole but was designed to provide an effective indication of their attitudes.

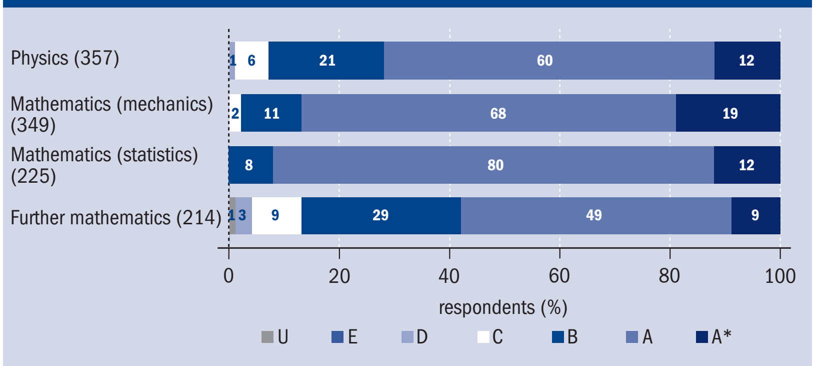
5: Main findings

Figure 1: Subjects studied at A/AS-level



Base: all students (393). Note: where students completed both A- and AS-level, only the higher qualification is taken into account.

Figure 2: Grades achieved at A/AS-level



Base: all students (393). Note: grades across A/AS-level have been combined.

5.1. Student profiles

This section expands on the sample information, giving information on the A- and AS-levels that the students who were interviewed had studied, and what grades they had achieved.

5.1.1. Subjects studied at A/AS-level

Students were asked to select what subjects they studied at A/AS-level (from a pre-coded list). Figure 1 shows the results.

During the case-study visits to the universities, students were asked to outline their rationale for choosing the A/AS-level subjects that they had studied. Some students reported that they were thinking about their future degree options when they made their choices, but many were not. These students tended to make their selections based on the subjects that they had enjoyed at GCSE, and what they had been advised by teachers to pursue based on their aptitude. A number of students had studied mainly scientific/mathematical subjects but decided to balance that out by studying an arts subject/foreign language. This was done not only to develop a broader range of skills, but also to ensure that they didn't spend all of their time working mathematically.

"[...] geography was just to round it out a little so I wasn't doing too much maths stuff basically. To get a few more essay writing skills as well."
Physics student

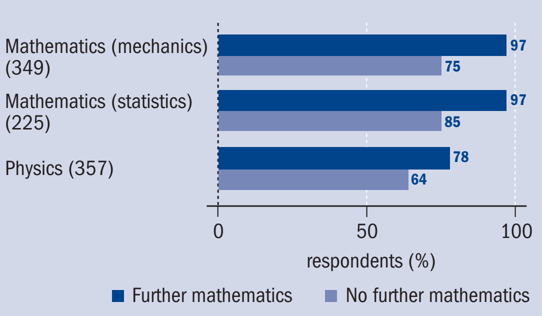
Students were asked to indicate what grade they achieved in each of the subjects that they studied. Figure 2 shows the results.

Students surveyed had achieved particularly high grades in mathematics subjects, with 87% of those that took mechanics achieving an A or A* grade, and 92% of those that took statistics achieving these top two grades. Grades achieved in physics were overall slightly lower, with nearly three-quarters (72%) achieving an A or A* grade; and just over half (58%) of students that took further mathematics being awarded these high grades.

In all cases, a greater proportion of those that had studied further mathematics achieved the highest two grades in other related subjects. This is illustrated in figure 3.

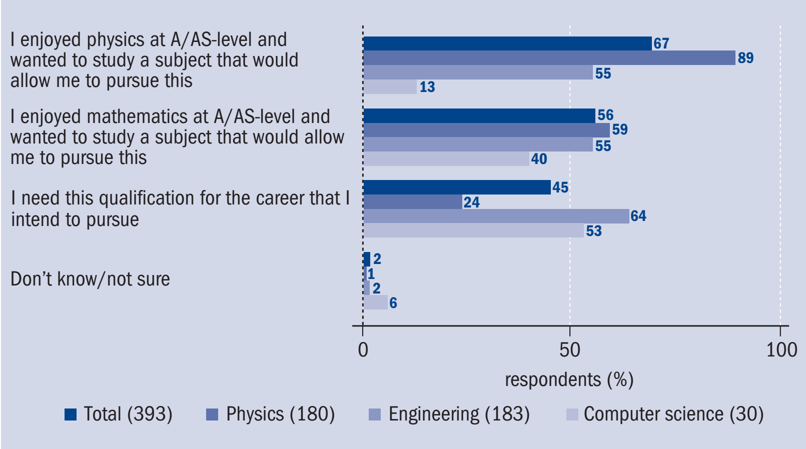
In the case of both statistics and mechanics, nearly all (97%) of the students that had taken further mathematics achieved an A* or A grade, compared to only three-quarters of mechanics students, and 85% of statistics students who had not taken further mathematics. This may be linked to the reasoning that the more able students were more likely to have studied further mathematics, but also corroborates an assertion made by a number of students inter-

Figure 3: Proportion of students achieving A* or A grades



Base: all students taking mathematics and/or physics A/AS-level.

Figure 4: Reason(s) for choosing degree course



Base: all students (393). Note: answers with an overall response of less than 5% have been excluded.

viewed during the case-study visits, who reported that studying further mathematics helped them with their general mathematics studies. Though the relationship was less marked on grades achieved for physics A/AS-level, over three-quarters (78%) of those that took further mathematics achieved an A* or A in physics, compared to 64% of those who did not take further mathematics.

"Starting my A-levels, I was thinking about what degrees I might want to do. My teachers said if you want to do maths or physics, you should try further maths, so that you're prepared for degree level. It made the A-level maths seem easier in comparison." **Physics student**

5.2. Reasons for choosing a physics/ engineering degree

This section will explore the rationale that students gave for choosing to study their particular degree course.

5.2.1. Reasons for choosing their degree course

Students were asked why they chose to study their degree course. Figure 4 shows the results.

Two-thirds (67%) of all students surveyed from all degree courses, stated that the reason for choosing their degree was that they enjoyed physics at A/AS-level, and they wanted to study a subject that would allow them to pursue this topic. Unsurprisingly, this was particularly influenced by physics students, among whom 89% gave this response. Non-physics students were more likely to indicate that they need their degree qualification for the career that they intended to pursue (engineering, 64%; computer science, 53%).

Just over half (56%) of all students indicated that a reason for choosing their degree course was an enjoyment of mathematics at A/AS-level. Physics students (59%) were more likely to cite this as a reason than computer science students (40%).

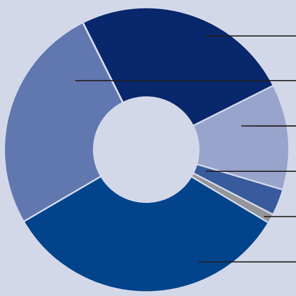
A number of physics students interviewed during the case-study visits expanded on the idea that physics allowed them to pursue their enjoyment of mathematics by adding that they felt it was more "applied" than studying straight mathematics, and as such, the perception was that it kept their future career options broader.

"I think that a physics degree is a lot more employable than a maths one, yet it still allows me to study maths to higher levels. I can still do courses from the maths department, even though I'm a physicist, so I can still study the pure maths as well." **Physics student**

"When I started looking round universities, they were always talking about the employability and the wide range of skills you develop and the many different areas you could go into. A lot of physicists go into business, whereas the more traditional aspects like teaching and research are still open to you. I did look around some maths departments and it wasn't the same, not so much emphasis on your employability, whereas every uni I went to to look at physics, they always tried to show that off." **Physics student**

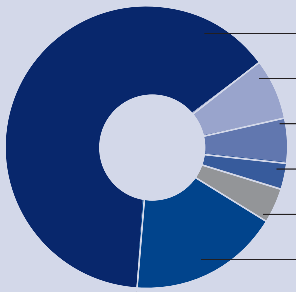
Engineering students interviewed qualitatively expanded on this by asserting that they perceived engineering to be broader again in terms of the skills that it offered them.

Figure 5: Physics students intended career paths



Base: all students (180).

Figure 6: Engineering students intended career paths



Base: all engineering students (164)*. Note: due to the structure of the questionnaire this was only asked to those engineering students that had selected a pre-coded engineering degree option at S5[2].

"I liked physics but it's not as useful a degree, not as practical as mechanical engineering." **Engineering student**

The perceptions of the "usefulness" or application of different degree courses came from a wide range of sources, including parents, teachers and university staff (at open days). Students also discussed their degree choices with peers.

5.2.2. Future intentions

Students were asked to indicate what career path they intended to follow. Figures 5 and 6 show the results.

Just over a quarter of physics students (26%) indicated that their plan was to work in a physics-related job after graduation, and slightly fewer (25%) reported an intention to study further in the field of physics. Nearly one-eighth (12%) intended to pursue a career unrelated to their field of study, and around a third of physics students responded that they didn't know what they were going to do after graduation.

This lack of direction among a significant proportion of physics students was supported to a certain degree by the qualitative interviews, whereby many physics students reported that they had not yet decided what they wanted to do after leaving university (only first- and second-year students were interviewed). Some respondents expressed an interest in entering the world of finance, as they had been told that their skills would lend themselves well to this path.

"[...] I'd prefer to work in the city, which a large section of physics students go into afterwards. I think the skill sets I've got, especially the maths and that kind of thing, is perfect to go into that." **Physics student**

"It would be nice to use the physics. You know that if you can't find something, lots of people want you because of problem solving." **Physics student**

Engineering students appeared more likely to stay in their degree field than physics students, with nearly two-thirds (63%) responding that they intended to work in an engineering-related job after graduation. Only 17% didn't know what they would do after they finished their degree.

Findings from the qualitative interviews were not quite as consistent as the quantitative feedback would suggest. A number of students were still undecided as to whether they wanted to become an engineer as such, though most agreed that they would want to do something that involved using their degree.

"When I was looking at a degree, I didn't look too deeply but most people that do maths or physics degrees have a specific target at the end that requires a maths of physics degree. Whereas an engineering degree just shows more the ability to think things through logically, so you can go into a lot of different fields. I'm 90% sure I don't want to do anything to do with civil engineering and I'm also not sure what I actually want to do. It just gave me a bit of time and flexibility to decide. It could seem like it opens more doors but it's not necessarily true. It's more something that you can get into a wider range of things." **Engineering student**

5.3. Expectations of their degree course

This section explores the expectations that students had of their degree course, specifically with regard to the mathematical content of their course.

[2] For a copy of the appendix please contact sophie.robinson@iop.org.

5.3.1. General expectations of their course

Students were asked to indicate to what extent their expectations of their degree course had, or had not, been met. This was asked as an open-ended question, and similar responses have been grouped together. Figure 7 shows the results.

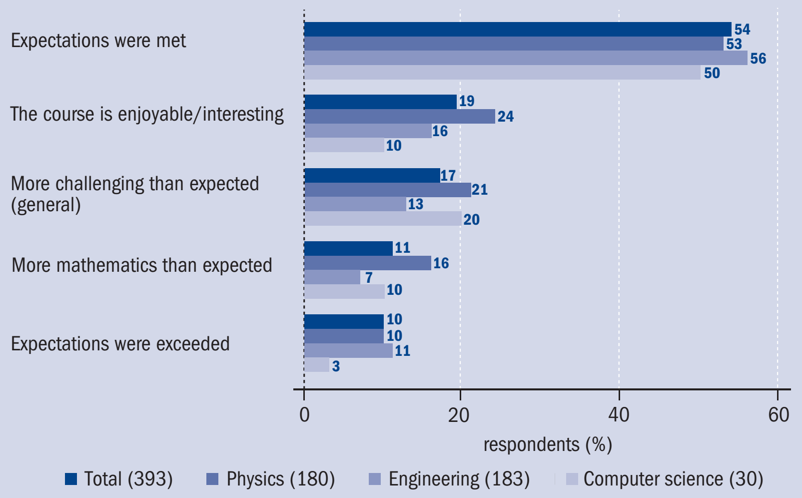
Just over half (54%) of all students indicated that their expectations of their course had been met, and just under a fifth (19%) answered that their course was enjoyable/interesting. A small proportion (17%) indicated that they had found their course more challenging than they had expected, and just over a tenth (11%) specifically responded that they had found the course to contain more mathematics than they had anticipated. This was particularly true of physics students, of whom 16% gave this response, compared to only 7% of engineering students. There was also a slight difference between first- and second-year students giving this answer, with 15% of second-year students expressing a degree of surprise at the amount of mathematics in their course, compared to 8% of first-year students.

Only 3% of students (the same percentage across all degree types) felt that their expectations of their degree had not been met.

Feedback from the qualitative interviews lent some context to the findings around student expectations of their degree course; many students talked about how they had thought less about the content of their degree than they had about all the other changes that going to university involved, such as leaving home and having to work more independently.

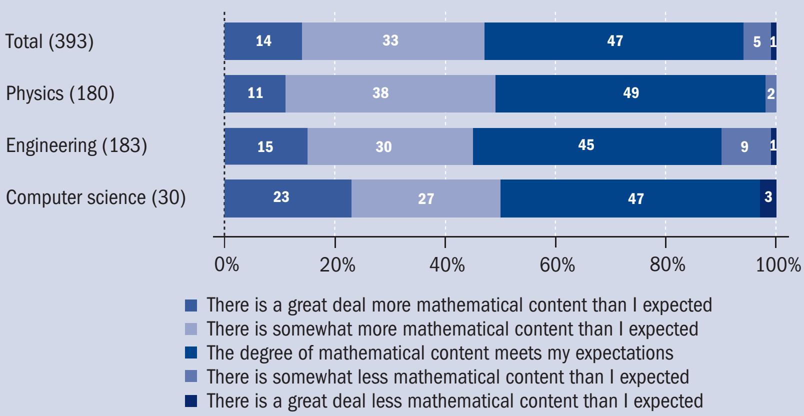
“I’m in my second year now. I think I found the step from first to second year bigger than the step from A-level to uni. I think coming from A-level to uni, so much is changing that you take it all in your stride and get on with it.” **Physics student**

Figure 7: Extent to which general course expectations were met



Base: all students (393). Note: answers with a response of less than 10% have been excluded.

Figure 8: Extent to which mathematical content of course has met expectations



Base: all students (393).

5.3.2. Expectations of mathematical content of their course

Students were asked to what extent the mathematical content of the course had met their expectations. Figure 8 shows the results.

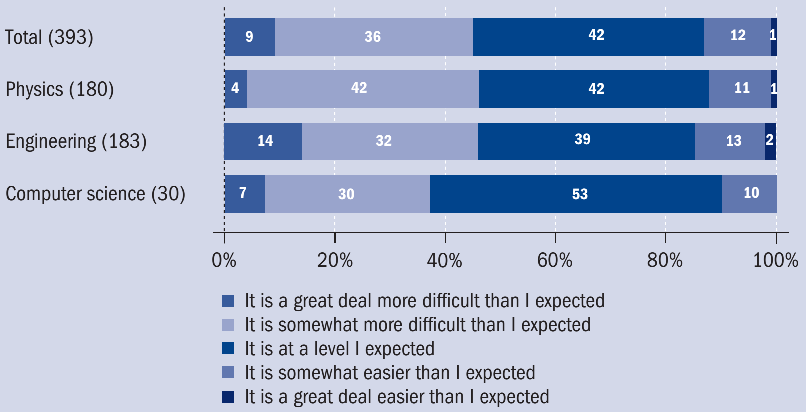
While just under half (47%) of all students responded that the degree of mathematical content in their degree had met their expectations, the same percentage felt that there was either somewhat more, or a great deal more, mathematical content than they had expected. This pattern was reflected to a similar extent across all of the degree types.

Mostly students commented that they had based their expectations on the amount of mathematics in their degree course on the mathematics content within their physics A-level.

“I didn’t anticipate the amount of theory there would be in the course. At A-level, physics is just simple maths with some descriptions of the final results of the maths (e.g. Big Bang) without the more advanced maths between. I wasn’t prepared for the amount of maths.” **Physics student**

“The amount of maths was a massive surprise. I’d expected it to be a little more practical, but obviously we have to get the foundations and everything. We’ve got all the maths lectures and you can’t always see how it links to your course,

Figure 9: Difficulty of mathematical content compared to expectations



Base: all students (393).

and then there's all the maths mechanics in every single other module as well, so it's pretty heavy, which I hadn't expected at all."
Engineering student

"The lack of any proper maths at A-level physics meant that I felt quite overwhelmed and had to learn the skill of deriving physical meaning from maths, something I'm still having to pick up on."
Physics student

Across all degree courses, those students that had studied further mathematics at A- or AS-level were more likely to have their expectations met with regard to the amount of mathematics in their degree, with only 38% indicating that there was more, or somewhat more, mathematical content than they had expected, compared to 57% of those that hadn't taken further mathematics.

"In first year I don't think I learned any new maths from A-level. It was packaged in a different way, but in terms of content, further maths provided everything you need. I've forgotten a lot but it wasn't generally new." **Engineering student**

Students were then asked, compared to their expectations, how easy or difficult they had found the mathematical content of their course. Figure 9 shows the results.

Overall, around two-fifths indicated that the difficulty of the mathematical content of their course had met their expectations. Almost half (45%) of all students responded that the mathematical content of their course was either somewhat more difficult or a great deal more difficult than they had expected.

Once again, those students that had studied further mathematics at A- or AS-level were more likely to indicate that the mathematical difficulty was at the level that they had expected, with 47% giving this response, compared to 35% of those that did not study further mathematics. Of those that had studied further mathematics, 16% felt that the mathematical content was a great deal easier or somewhat easier than expected, and around one-third (36%) felt that it was somewhat more difficult, or a great deal more difficult, than expected (compared to 56% of those who did not study further mathematics).

This finding was supported in the qualitative interviews, whereby students who had studied further mathematics reported this having helped them with the mathematical content of their course, and those that hadn't suggesting that they had struggled more as a consequence.

"Even though I didn't do particularly well in further maths, I think it's prepared me for some of the stuff that we got to do at the first year of degree level."
Physics student

"In general, [it's] harder than expected, especially the mathematical aspects. I felt thoroughly unprepared for the mathematics involved coming from only having maths (no further maths) A-level. My peers who did study further maths were much better prepared." **Engineering student**

One student who was interviewed also indicated that having needed to take "STEP" as part of an application to Cambridge (where he did not eventually attend), had introduced him to mathematics taught in a different way to A-level, which had helped him. He suggested that the teaching of STEP was more in-depth than A-level and as such was more similar to the style of teaching at university.

5.4. Teaching of mathematical content

All students interviewed during the case-study visits (with the exception of those studying mathematics and physics joint honours, whose mathematical modules were covered by the mathematics department) reported being taught mathematics within their department (i.e. mathematics for engineering taught by engineers and mathematics for physics taught by physicists), though there was some degree of uncertainty around what department was responsible for this. This ensured that the mathematics was taught within the context of their degree, with references made to how the theory applied to their course. The importance of this context was underlined by a group of engineering students at one university who discussed the fact that their mathematics is taught to all engineers together, regardless of their specific engineering discipline. It was suggested that this makes it difficult for lecturers to give examples that relate to the modules studied by all students, which can impact on both understanding and motivation to learn.

"The difficulty is it's all the different disciplines of engineering together, so even if they give an example, it might be an aero example, and we're like 'we don't want to build an aeroplane'. I'm sure if they explained it to us we would see how it was relevant, but sometimes we're just sitting there like 'we're not doing maths, we don't need to know how to integrate complex numbers' or whatever. We can't see how it links in, and then it's difficult to get the motivation." **Engineering student**

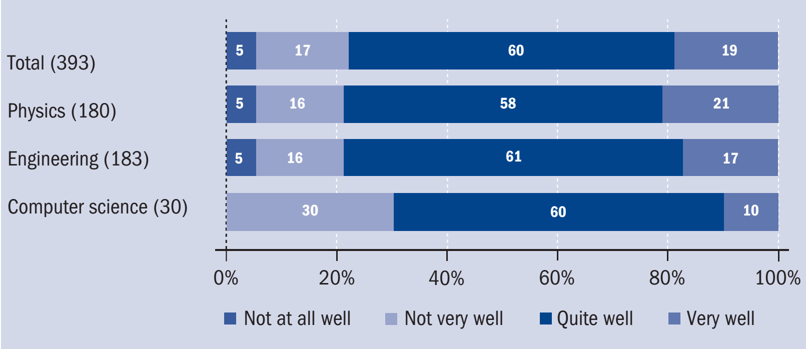
The vast majority of the academics surveyed indicated that the mathematical content of their degree was taught within their department (though expanded that theoretical physicists tend to be taught mathematics from the mathematics department, in addition to the joint honours students). However, some academics fed back that there was a "service department" that delivered some mathematical content to their students. For example, a module called "engineering mathematics" was taught to the engineering students at one university by staff from the mathematics department. One academic described why they didn't think that this was as viable an option as mathematics taught within their own department:

"We gave up service teaching by maths in 2001 when this course was created. There was a strong pedagogic reason for it. Most maths lecturers that we had in teaching engineering students taught them maths, and that's not what's needed. We needed to inspire them and get them to understand why they were learning the maths. The language of maths to a mathematician is different to that of engineering maths. We put the maths into an engineering context as a lot of the problems look like real problems in engineering, so students can see why they're learning it."
Engineering academic

5.5. Ability to deal with mathematical content of course

This section will explore the students, and academics, perceptions of how well they have dealt with the mathematical content of their course, including specific information on what they have found particularly easy or challenging.

Figure 10: Perceived ability to deal with mathematical content of degree course



Base: all students (393).

5.5.1. Student feelings around their ability to deal with mathematical content of degree course

Students were asked to rate their ability to deal with the mathematical content of their degree course when they started. Figure 10 shows the results.

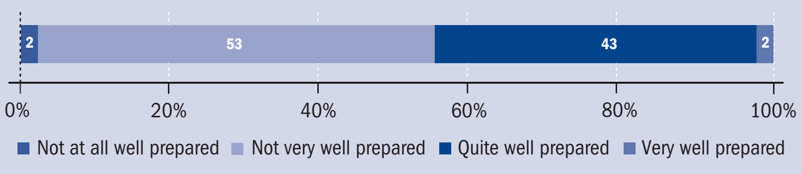
Nearly four-fifths (79%) of all students perceived that they were able to deal either very well or quite well with the overall mathematical content of their course when they started. This rose to 88% among those students that had studied further mathematics at A- or AS-level (compared to 66% of those who had not).

This finding was supported in the qualitative interviews. The majority of students felt that while the volume of mathematical content had been somewhat surprising, they felt that on the whole they were able to adapt quite well to it. Very few considered it to be an issue in terms of their progress on the course. As indicated by the quantitative findings, this was especially true for those that had studied further mathematics.

"I didn't know there would be this much maths, but I'm generally alright with it, because I've done further anyway. So it's not too bad."
Physics student

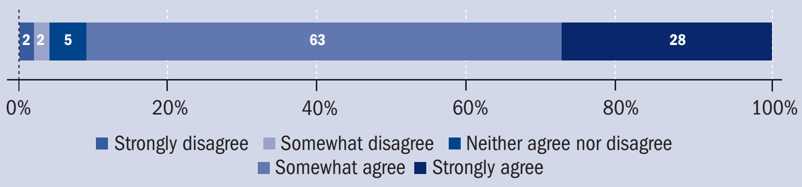
However, there was a sense that towards the end of the first year, and into the second year, that the mathematical content became harder for all students, regardless of whether they had studied further mathematics or not. This was felt to be partially related to the idea of moving away from content with

Figure 11: Preparedness of first-year students to deal with mathematical content



Base: all academics responding (40).

Figure 12: Extent to which students joining course felt that they lacked fluency in mathematics



Base: all academics responding (40).

which students were already familiar, and also that the pace at which the content was being covered seemed to be quickening.

"I found that the first semester was alright. A couple of them, I'd taken before at A-level, like further maths and stuff. The second semester has been a lot harder. Now we've started covering new topics that I've never seen before. In the first semester it's quite easy to switch off but still manage to get good marks. I could go back to my A-level work and use that, whereas now I'm struggling a bit more. It's still manageable but it's a lot harder in the second semester because you're not recapping. The new ground you cover is pretty difficult to be honest." **Physics student**

5.5.2. Academic perceptions of students' ability to deal with the mathematical content of a degree course

Academics were also asked to rate how well prepared they felt first-year undergraduates were to deal with the mathematical content of the course. Figure 11 shows the results.

Academics appear to have a slightly less positive view on the preparedness of students than the students themselves, with over half (55%) indicating that they feel that their first-year students are not very/ not at all well prepared to deal with the mathematical content of their course. In fact, a number of academics suggested that the students don't admit to having a problem, or if they do, not really understanding what issues they have.

"They don't usually admit that they've got a problem. They don't quite understand what problem they've got. They know they are not quite understanding it but they can't pinpoint where the problem lies." **Engineering academic**

Academics were also asked to what extent they agreed or disagreed with the idea that students joining their course lacked fluency in mathematics. Figure 12 shows the results.

The vast majority of academics surveyed (91%) agreed that the students joining their course lacked fluency in mathematics. Those 91% were asked what proportion of these first-year students lacked fluency. Table 1 shows the results.

While academic estimations on what percentage of their students lacked fluency ranged from 15–75%, average statistics indicate that, overall, less than half of first-year students are felt by academics to lack fluency in mathematics.

According to those academics interviewed, almost all incoming students could be said to lack fluency to some degree, but it is felt to only be an issue worth addressing for a small proportion. For an even smaller percentage again (around 5%), the issue is never really overcome, and can be an obstacle throughout the course.

"Mostly they've covered a wide and appropriate range of mathematical concepts and techniques. I do think they lack practice and fluency. I think many of them have a rather poor feel for numbers and find it very difficult to do estimates, quick checks, if there is a reasonable answer [...] I think they're quite poor at unstructured problem solving" **Physics academic**

Academics interviewed qualitatively talked at length about why they felt students struggled with the mathematical content of their degree courses. Much of the issue was felt to be symptomatic of the way that mathematics is taught at A-level, and earlier in school.

"Deep down, the problem is, mathematics is a language that they don't speak because they are not taught to speak it. Why should they think it is so important if they haven't been taught to speak it properly? You can imagine when you present physics material, which is all equations, they just go bonkers. You need to have competence in mathematics to explain the concepts. They say the equations are so difficult, they don't get the point

Table 1: Proportion felt to lack fluency in mathematics

	% lacking fluency
Range	15–75
Mean	39
Median	35
Mode	30

that it is not the equations that are difficult, it is the concept that is difficult. You can harness extremely complicated concepts into one equation, this is the power of mathematics. They don't seem to get that because they are not being taught in that way. There is an over-simplification of mathematics at every age." **Engineering academic**

Teaching to exams

A number of academics felt that mathematics was taught too heavily to exams at A-level – in so far as students are taught to learn various equations and techniques by rote in order to pass exams, rather than being taught how and why the equations have been developed.

The feeling among most academics was that this can lead to a lack of understanding of the context in which mathematical techniques can and should be applied, and could also lead to a "narrow" view of when and where certain techniques should be used – it is felt that too many separate equations are taught when actually there are only a few key ones from which others can be derived.

"I always say you often see equation democracy. If you look at A-level maths textbooks nowadays they look like every equation is as important as every other equation. The only way you could possibly do maths is to memorise every equation in the world, whereas there are relatively few equations that are important. If you know those and know what they mean, typically you can get the others. What I have seen of the A-levels, in some places there is like a hierarchy problem. There is no understanding that this thing is really important, this is central and you get other things from this." **Physics academic**

The feeling was that if A-level students were taught this they would have better contextual and intuitive understanding of mathematics, which would then increase their mathematical dexterity. The view among academics surveyed was that students struggle with the "unstructured" nature of problem solving at degree level – they are accustomed to being told to solve a certain equation, rather than being asked to solve a problem and having to identify what techniques need to be employed to achieve this.

"The style of teaching that we have at A-level, globally, the teaching of mathematics is taught in a mechanical fashion. That results in scant ability for exertion and an extremely poor ability to manipulate. They have only learnt things mechanically and not quite grasped the essence. Mathematics is a language, instead for them it is a language they do not speak, an enemy."
Engineering academic

"They're poor, firstly, at identifying where they need to start. They can't always think. They think of it as thinking of the right equation. I think of it as being able to formulate the problem mathematically. I think they're rather weak at that and at multistep problems, where you need to work through a number of steps, perhaps half a dozen, of a calculation to get to the answer. I think they are much more used to very structured problems where they are told something and told to calculate something that follows, and then something else that follows from that, and then something else that follows from that, and they're lead through step by step. I think they are quite weak at multistep problems. I think it's the way they've been taught and examined, which are quite highly interrelated actually." **Physics academic**

Students also offered thoughts along the same lines, talking spontaneously around how the mathematics teaching/learning style at university is very different to that encountered in the school environment.

"I was startled by how different university-level maths is, lots more rigour. I wasn't very well prepared for this by my school's teaching to pass exams." **Physics student**

Compartmentalisation

A number of academics also alluded to the "compartmentalisation" of mathematics and physics at A-level. Some feedback indicated that mathematics and physics are treated as being too distinct; there was seen to be minimal crossover in terms of syllabus, when in reality there should be a great deal. This leads to students reporting that they are not familiar with a particular technique/equation in a physics/engineering context, but later realising that they are aware of the technique but, having learned it in mathematics, were unaware that it could be applied in a different context.

"If you learn technique A in a unit, let's say, in a module on technique A, you are never ever expected to use it in a course or module in something different. So there's absolutely no transferable skill that they are learning. It's amazing, you can actually ask somebody a question, and they say, 'I have no clue how to answer that', and we say, 'Haven't you seen this before?' 'Yes. You mean I can use this piece of maths to solve this piece of physics? Wow.' They can do it, potentially, when prompted, most of them. They shouldn't need to be prompted. They've never seen maths as a toolbox for physics before. It is purely down to compartmentalisation."
Physics academic

This is also linked to the "learning by rote" point above.

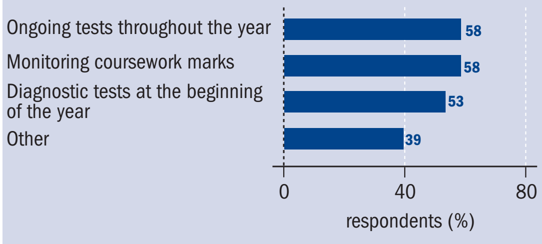
Academics interviewed were also asked whether any students left their course as a result of the perceived difficulty of the mathematical content. While a small number (ranging from around 5–15%) do leave the course within the first year, this cannot be directly attributed to a struggle with the mathematics, but more an overall difficulty with the course or a decision to pursue other avenues.

Academics were also asked if there were any markers that they used to be able to anticipate how well students would adapt to the mathematical content of their degree. Most felt that A-level results were not a reliable marker of how well equipped the students would be as their admission criteria has been steadily getting narrower, so they are only getting the most able students anyway.

Academics agreed that further mathematics often helped students to assimilate to the content more quickly as they had covered a broader range of subjects, and had had more practice, which made them slightly more fluent.

"The content [of further maths A-level] is clearly helpful. In their first semester here, a lot of the maths that we're teaching them is essentially the content of A-level further maths, because we take students who haven't had [further] maths. So they have a gentler lead in and more time to get used to the differences in style and shape of problems that we're asking them to tackle." **Physics academic**

Figure 13: How mathematical ability is assessed



Base: all academics responding who assess mathematical ability (36).

However, some felt that this could lull students into a false sense of security as they didn't feel that they had to work as hard as those that didn't have that qualification, which would not prepare them well for their second year of study where the playing field would be more level (as all content would be new to all students).

"The further maths, certainly, gives them a bit of breathing space. I think my maths colleagues worry, however, that it might lull them into a false sense of security. In a sense, those who haven't got the further maths, being thrown in more at the deep end, become a bit more resilient. Perhaps they're forced to cultivate better learning habits."
Engineering academic

Some students interviewed qualitatively echoed these feelings.

"If I hadn't done further maths, I think I would have struggled more with the first semester, but then I would have struggled less with the second semester because I'd have been in the zone. They do teach you really well in the first semester. A lot of my friends who didn't do further maths did really well in the first semester, and now they're much more comfortable than I am with the second semester." **Physics student**

There were not seen to be any other particular markers for aptitude; including around differences between genders. Female students interviewed did not feel that they were at a disadvantage.

5.5.3. Academics' assessment of students' mathematical ability

Academics were asked if they assessed their incoming students' mathematical ability during their first year. The vast majority (90%) said that they did, 7%

said that they did not, and 3% reported that they didn't know.

Those 90% who said that they did assess students' mathematical ability were asked how they did this. Figure 13 shows the results.

Over half (58%) of academics assessed mathematical ability through on-going tests throughout the year, or monitoring coursework marks. Slightly fewer (53%) reported that they carry out diagnostic tests at the beginning of the year. Of those 39% of academics who responded that they use other methods of assessing mathematical ability, around half described other types of tests that are carried out at various stages throughout the academic year.

5.6. Reactions to specific mathematical elements

This section explores in more detail the reactions to specific mathematical elements of physics and engineering degree courses, from the perspective of both students and academics.

5.6.1. Students' reactions to specific mathematical elements of the course

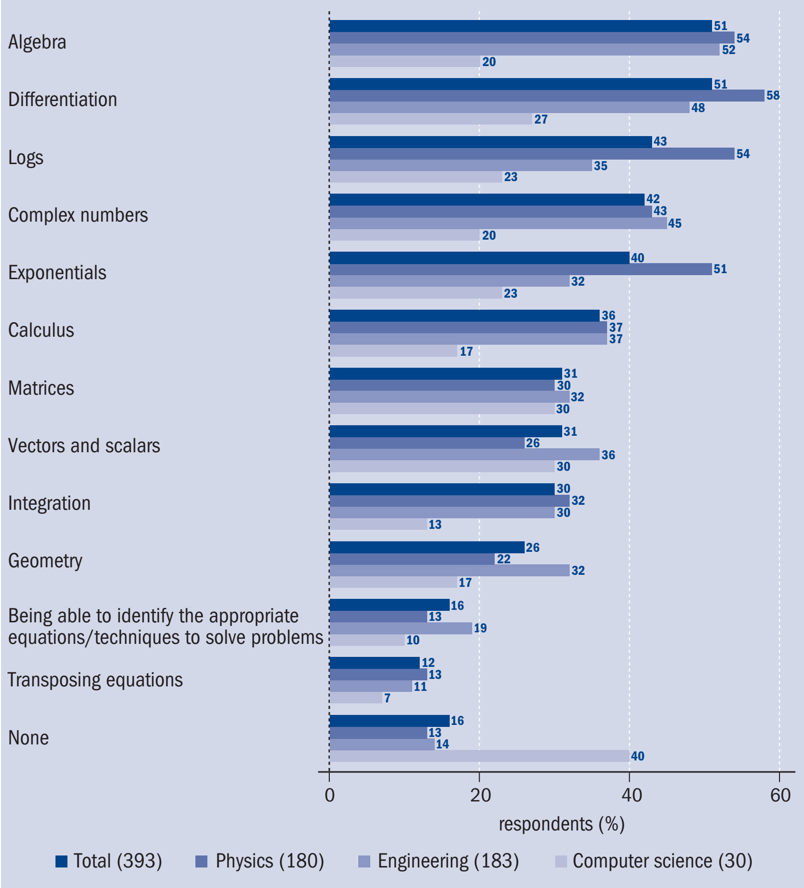
Students were asked to indicate whether they had found any elements of their course particularly easy or challenging. Figures 14 and 15 show the results.

Algebra and differentiation were most commonly chosen as being particularly easy by all students, with around half of all students (51%) selecting these elements. This was particularly true of physics students, among whom 54% indicated that they found algebra particularly easy, and 58% found differentiation easy. Physics students were also more likely than other students to find logs (54%) and exponentials (51%) particularly easy. Engineering students were more likely than those studying other degree courses to rate geometry (32%) as being particularly easy. Computer science students were by far the most likely to indicate that they found none of their course particularly easy (40% compared to physics, 13% and engineering, 14%).

Students that had studied further mathematics at A- or AS-level were more likely to rate complex numbers as particularly easy (49% compared to 34% of those that hadn't studied further mathematics), as well as matrices (42% compared to 18%).

Just over two-fifths (41%) of all students indicated that they found integration to be a particularly challenging element of their course. This was particularly driven by engineering students, 45% of whom selected this element, compared to 40% of physics students and 23% of computer science students.

Figure 14: Mathematical elements that students have found particularly easy



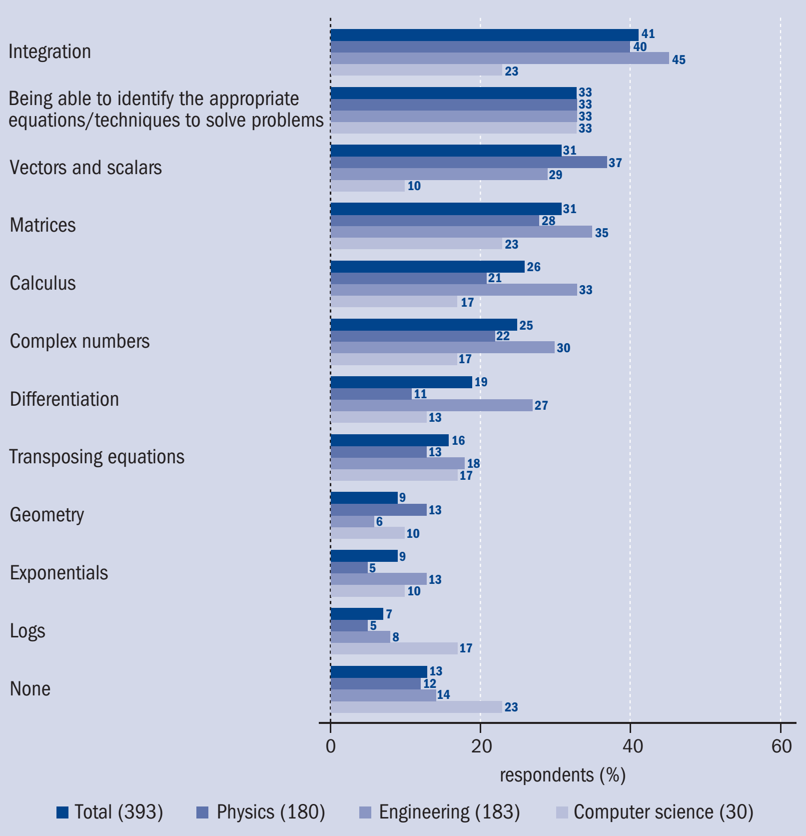
Base: all students (393). Note: answers with a response of less than 10% have been excluded.

Around one-third of all students (33%: the same proportion across all degree courses) indicated that they found being able to identify the appropriate equations/techniques to solve problems to be particularly challenging, a finding that was echoed by many who were interviewed qualitatively.

"Translating from the mathematics to a physical implication. Identifying appropriate equations/ techniques seems to be more 'experience'-based than 'understanding'-based, like spotting certain grammatical structures in a language. I think that lecturers are generally unaware (or have forgotten) that 'spotting' solutions comes naturally only after extensive practice, and that the correct problem-solving approach is not immediately evident to the untrained eye." **Engineering student**

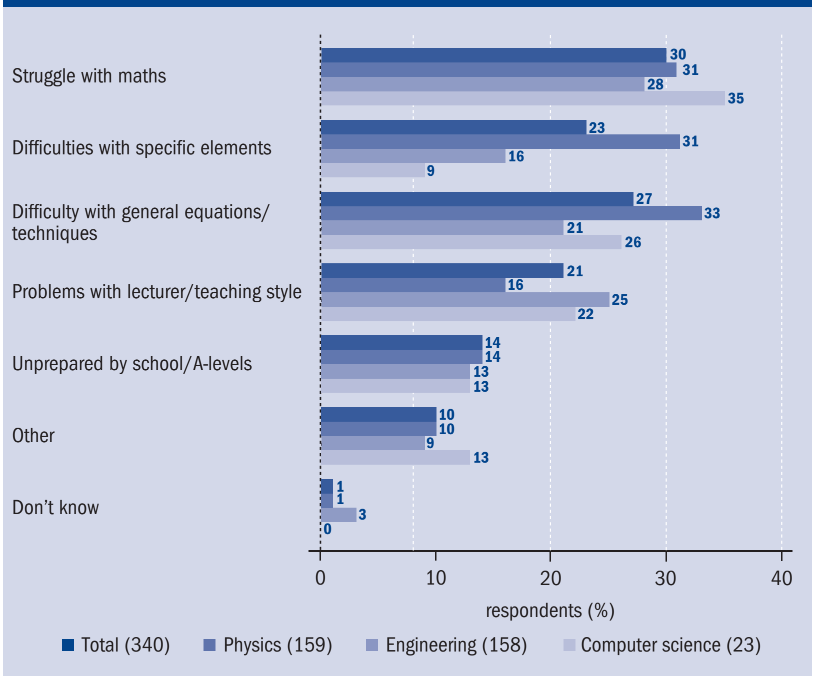
This was also more commonly chosen by second-year students than first-year students (39% compared to 29%). For some the issues lay more with the material itself being new.

Figure 15: Mathematical elements that students have found particularly challenging



Base: all students (393). Note: answers with a response of less than 7% have been excluded.

Figure 16: What they found challenging about the topic(s)



Base: all students who indicated that they found an element of the mathematical content challenging (340). Note: small base size for computer science.

"I think the reason I found these topics challenging was that mathematically they were completely foreign. I had not been exposed to it at A-level and at first even the simplest of matrices and complex number problems seemed difficult. The nature of introductory lectures in a physics course is to go through the basics as if no one has any background knowledge but rapidly move away from this to harder examples and more difficult techniques. This generally isn't an issue for calculus, integration and differentiation for example as you have been given an understanding of the basic concepts at A-level. But grappling with strange and unusual concepts while quickly being exposed to problems that far surpass A-level difficulty can be a challenge." **Physics student**

"It also depends a bit on what modules you did within your maths A-level. I didn't do anything involving matrices and there have been a lot of matrices this year. Things like complex numbers, in the straight A-level, there wasn't really anything to do with that, whereas that's quite a big part of, especially quantum mechanics. It's not just the maths side of things. Even in the physics and the core things, there are a lot of further maths concepts." **Physics student**

Those students who indicated that they had found any element of the mathematical content difficult were asked what it was about that element that they found challenging. Figure 16 shows the results.

Of those students who reported that they had found at least one element of the mathematical content of their degree challenging, nearly a third elaborated on this with rationale around struggling with the mathematics – this incorporated comments on the amount of mathematical knowledge that was required/assumed, the volume of new content, and the volume of content overall.

Those that commented on having difficulties with specific elements (primarily driven by physics students, of whom 31% gave this reason) mostly elaborated by saying that they had struggled to get to grips with that particular technique due to its complexity.

Around a third of physics students (33%; compared to engineering, 21%; computer science, 26%) gave a response that centred around having difficulty with equations/techniques. These remarks were based around finding it difficult to remember all the equations/techniques, when to use them, and how to apply them.

A quarter of engineering students (compared to physics, 16%; computer science, 22%) indicated that they had a problem with the teaching style of their lecturer. These responses tended to focus on the techniques not being covered in enough detail or being "rushed through" too quickly. This was supported to a degree in the qualitative interviews, but appeared to be less focused on the skill of the lecturer, and more around the speed at which they moved through the topics. Many students found it hard to keep up, especially with the amount of reading that they needed to do between lectures.

"They're hitting you with stuff that is very new and also they assume that you can remember everything from the first year. So we have to solve differential equations in our head, which is scary. You get used to it the more practice you get. It's just keeping on top of things."
Physics student

There was also a suggestion from a small number of students that mathematical notation can differ from lecturer to lecturer, and even within lectures (separate problems written with slightly different notation). This can lead to even further confusion.

Results from the quantitative survey showed that some students agreed with the academics' assertion that A-levels did not prepare them well for their degree, with 14% of all students spontaneously offering an answer along these lines.

"I find it quite a big step up from A-level. You can learn for your A-levels, you don't have to know stuff. You just revise and muddle through, and get an A-level, then get to uni and be like 'I didn't actually know that'." **Engineering student**

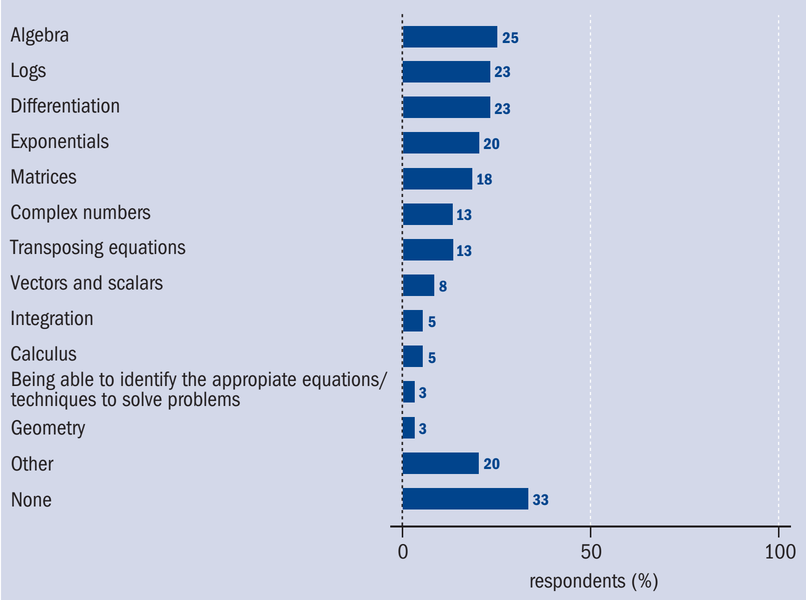
5.6.2. Academics' perceptions of students' specific abilities

Academics were also asked to indicate whether they felt that their students found any elements of their course particularly easy or particularly challenging. Figures 17 and 18 show the results.

It appears that academics' perceptions of the specific elements of mathematical content that students find particularly easy is more or less in line with what the students reported, with around a quarter selecting algebra, logs and differentiation, which also featured in the top three of the students' list. Around a third (33%) didn't feel that their students found any element of the mathematical content easy, compared to 16% of all students.

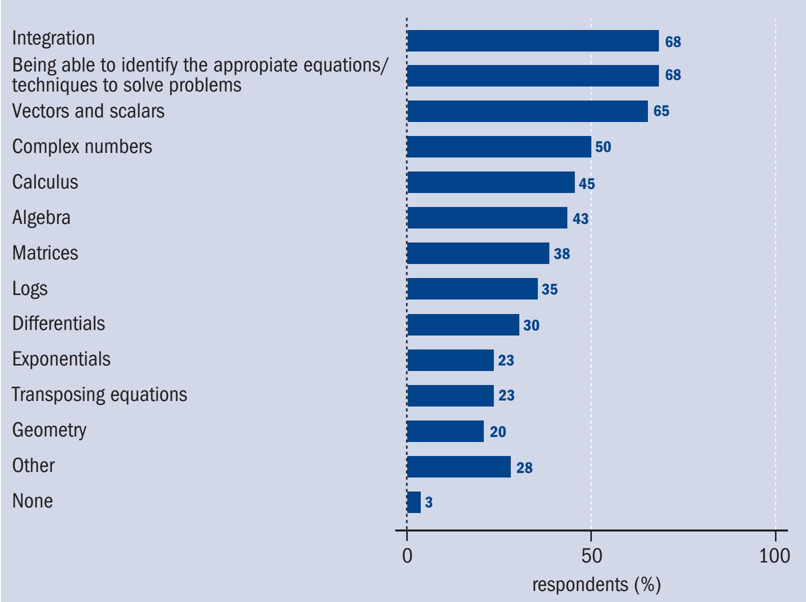
Academics perceptions of which elements students found particularly challenging were also in line with student feedback, as the top three selected options that match exactly what was selected by the students. Over two-thirds (68%) highlighted integration and being able to identify the appropriate equations/techniques to solve problems as particularly challenging for students. Slightly fewer (65%) indicated that vectors and scalars were seen to be a particular challenge for students.

Figure 17: Academics' perceptions of mathematical elements that students have found particularly easy



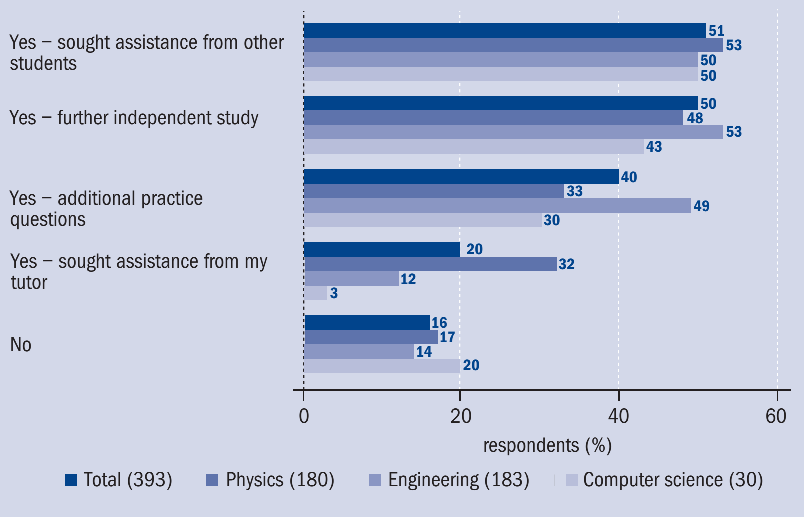
Base: all academics responding (40).

Figure 18: Academics' perceptions of mathematical elements that students have found particularly challenging



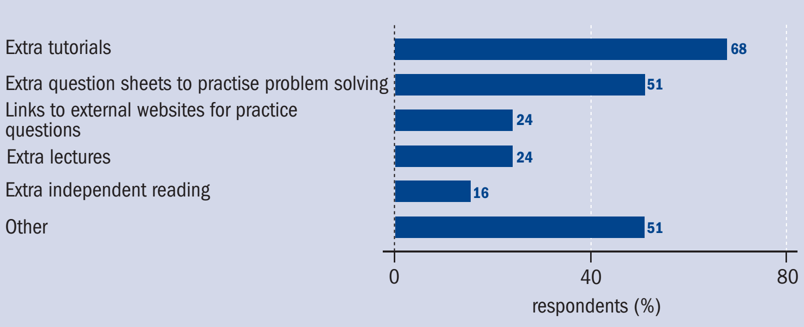
Base: all academics responding (40).

Figure 19: Whether students have taken independent measures



Base: all students (393). Note: answers with a response of less than 5% have been excluded.

Figure 20: Specific support offered to deal with mathematical contents of degree – academics



Base: all academics that said that their department/school offered additional support (37).

5.7. Dealing with mathematical content of course

This section explores how students have gone about dealing with the mathematical content of their course, including feedback from academics on the support that has been offered to students at their university.

5.7.1. Independent measures taken by students

Students were asked if they had taken any independent measures to help them deal with the mathematical content of their degree. Figure 19 shows the results.

The vast majority (84%) of students responded that they had taken some sort of independent measure to help them with the mathematical content of their degree. The most common responses were to have sought assistance from other students (51%) and to have done further independent study (50%). Engineering students were more likely than physics students to indicate that they had done additional practice questions (49% compared to 33% physics students).

Those that had studied further mathematics were less likely to have taken independent measures (79% compared to 91% of those that hadn't studied further mathematics). This fits with the idea outlined earlier, that students who have studied further mathematics don't feel the need to try as hard in relation to mathematics.

5.7.2. Academics' reports of support offered

Academics were asked whether their school/department offered any additional support to help their first-year students deal with the mathematical content of their degree.

Nearly all (92%) did, with the remaining 8% saying that they did not. Those who said that they did offer some form of support were asked what form this support took. Figure 20 shows the results.

Over two-thirds of academics (68%) said that their department/school provided additional support in the form of extra tutorials, while around half (51%) reported providing extra question sheets to practise problem solving. Just under a quarter (24%) of the academics responding to this question mentioned offering links to external websites for practice questions, or extra lectures. The "other" forms of support that were mentioned by the 51% consisted of problem classes, streaming of students into different mathematical ability classes and providing drop-in sessions for mathematics skills.

During the qualitative interviews, academics reported that they revised most of the A-level syllabus during the first year of study (albeit in an accelerated format), as well as explaining how the theory and techniques of what students have already learned apply to physics/engineering. This was not necessarily regarded as "additional" support, as it applied across the board.

These academics that offered additional support were also asked to outline how long their department had been offering it. Figure 21 shows the results.

Nearly half (49%) of the academics that said that their department/school offered additional support had been offering it for over six years (with 30% offering it for more than 10 years).

5.7.3. Student perceptions of support offered

All students were asked to indicate whether their university had offered them any support around the mathematical content of their degree. 83% of all students indicated that they had been offered support; 5% said they hadn't, and 11% responded that they didn't know.

Those that indicated that their university had offered them support were asked what form of support had been made available to them. Figure 22 shows the results.

The most common type of support offered to students was extra tutorials, with nearly two-thirds (62%) indicating that this had been made available to them. This was particularly true of engineering students, with 69% selecting this option, compared to 58% of physics students. Over half of students (56%) reported that they were offered extra question sheets to practise problem solving.

Those students that reported that they had been offered support were asked if they had taken advantage of it. Just over half (58%) said that they had. Those that had not studied further mathematics were slightly more likely to say that they had taken advantage of this support, with around two-thirds (66%) selecting this response, compared to 51% of those who had studied further mathematics.

Those students who had been offered support but hadn't taken advantage of it were asked why. Figure 23 shows the results.

The most popular reason that students gave for not taking advantage of the additional support was that they didn't feel that they needed to as they didn't have a problem. This was particularly true of physics students, of whom 69% gave this answer, compared to 43% engineering students. Those that had studied further mathematics were also more likely to indicate that they didn't need any additional support, with nearly two-thirds (64%) giving this response, compared to 45% of those that hadn't studied further mathematics.

5.7.4. Usefulness of different forms of support

Those students that had taken advantage of the support that was offered to them were asked which form of support had been the most useful. Figure 24 shows the results.

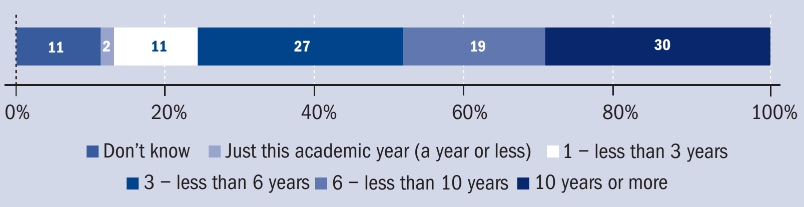
Around a third of all students (35%) chose extra question sheets as the most useful form of support that they had received from their university. One quarter (25%) indicated that extra tutorials were the most useful form of support for them. When combining forms of support that involves face-to-face contact time (tutorials, lectures etc) and separately combining those that involve "self-help" such as extra reading and question sheets, it emerged that more students chose self-help options in comparison to face-to-face support (52% compared to 31%). Engineering students were particularly likely to indicate a preference for self-help options, with 56% of them choosing these options compared to 49% of physics students.

Those students that had taken advantage of the support that was offered to them were then asked whether this support had sufficiently addressed the issue. Four-fifths (80%) agreed that it had, with those that had indicated self-help methods being the most useful being slightly more likely to respond that their issues had been addressed than those that chose face-to-face support (84% compared to 79%).

5.7.5. Further support needed – students

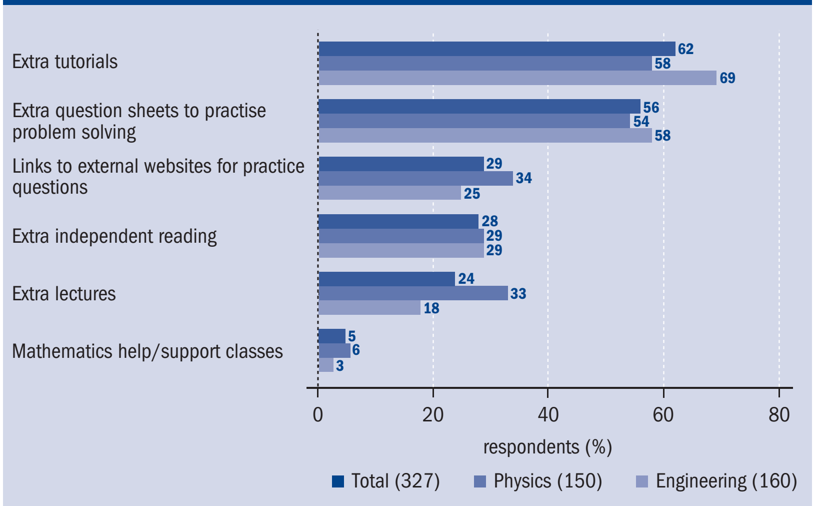
Students were asked an open-ended question on what else they felt could have been done to help them to deal with the mathematical content of their degree, either before they started their course or during their first year of study. Figure 25 shows the results (similar answers have been grouped together).

Figure 21: How long the department has been offering additional support



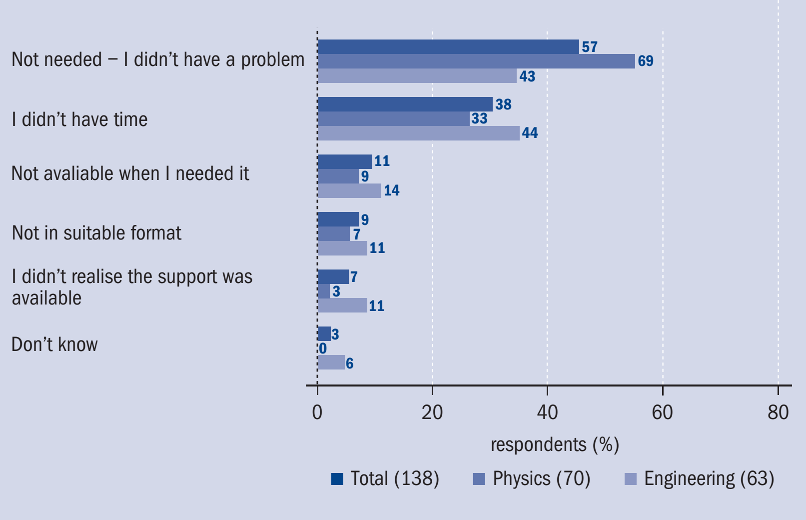
Base: all academics that said that their department/school offered additional support (37).

Figure 22: Specific support offered to deal with mathematical content of degree



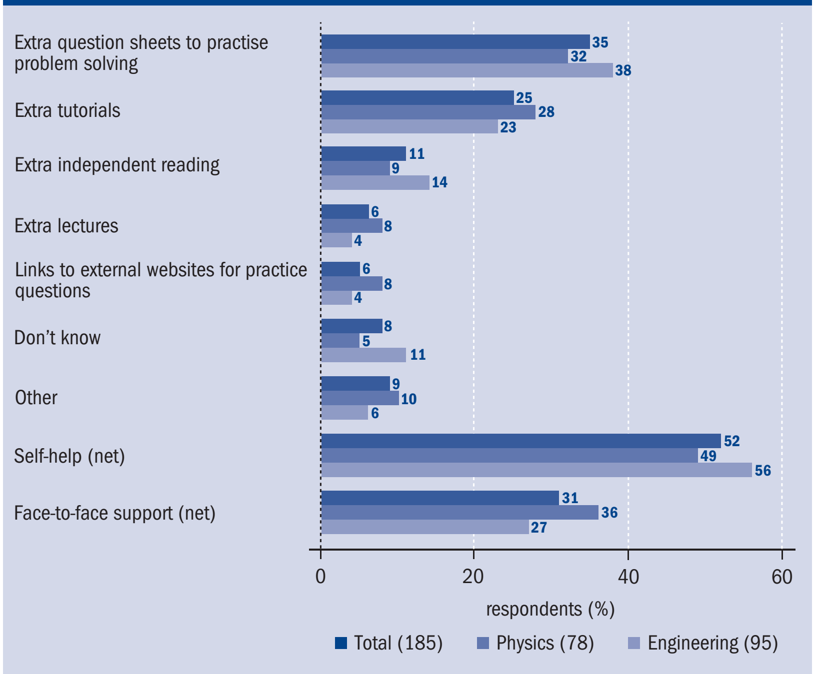
Base: all students that had been offered support (327). Note: answers with a response of less than 5% have been excluded. Computer science students have not been reported separately due to small base size.

Figure 23: Reasons for not taking advantage of support offered



Base: all students that had been offered support but did not take it (138). Note: answers with a response of less than 7% have been excluded. Computer science students have not been reported separately due to small base size.

Figure 24: Most useful form of support



Base: all students that took advantage of support offered (185). Note: computer science students have not been reported separately due to small base size.

Just over one-fifth (21%) of students felt that no further support was needed to help them with the mathematical content of their degree. This was a more common response among those that had studied further mathematics (29% of whom gave an answer along these lines, versus 11% of those who had not studied further mathematics). Just under a third (29%) of all students gave an answer that involved the university offering more support, such as more tutorial sessions, problem classes and example sheets. Interestingly, physics students were more likely to respond that they felt changes should be made to A-levels than engineering students (physics 16% compared to engineering 6%).

One-tenth of all students also mentioned that they felt studying further mathematics at A- or AS-level would be useful in terms of coping with the mathematical content.

The qualitative interviews confirmed these findings, but a number of students also indicated that it may have been useful to have received more guidance on what topics their course might cover, even to have some sheets of problems to get them "back up to speed" following the summer break. This was an even keener issue for those students that had taken a gap year.

"We had the long break between A-level and uni with nothing to do. They could have told us what would be our topics for the next year, so we could have a look if we wanted. I had no idea what I was going to be studying when I got here, until I got my timetable." **Physics student**

5.7.6. Further support needed – academics

The 92% of academics whose department/school offered additional support were asked whether they felt that this additional support sufficiently addressed the issue of lack of fluency in mathematics. Just over two-fifths (41%) felt that it did, with the remaining 59% answering that they did not feel it sufficiently addressed the issue.

All academics were then asked what else they felt could be done to help their first-year students to deal with the mathematical content of their degree, either before they started the course or during their first year of study. Many academics suggested that the ideal (though perhaps unlikely) scenario would involve changing the A-level mathematics syllabus to cover more concepts, and also to change the way in which it is taught in order to allow for more independent learning techniques, and less of a step-by-step approach.

"Change the way maths is taught at A-level; provide the fundamentals, not just recipes to apply in specific cases." **Academic**

Another popular proposed change to A-levels was to de-compartmentalise the mathematics and physics A-levels; to highlight the crossover to students at a younger age, so that they learn to apply what they have learnt in mathematics to their physics studies.

"Introducing more mathematical, problem-solving type questions into the physics A-level seems more appropriate. Getting across the importance of maths and practising how it is used in physics would be very valuable."

Potentially, a more realistic wish was for the benefits of studying further mathematics to be made clearer if students know that they will go on to study physics or engineering, as this (with the caveat that it shouldn't allow students to be lulled in to a false sense of security) appears to be helpful to students, particularly in their first year of study.

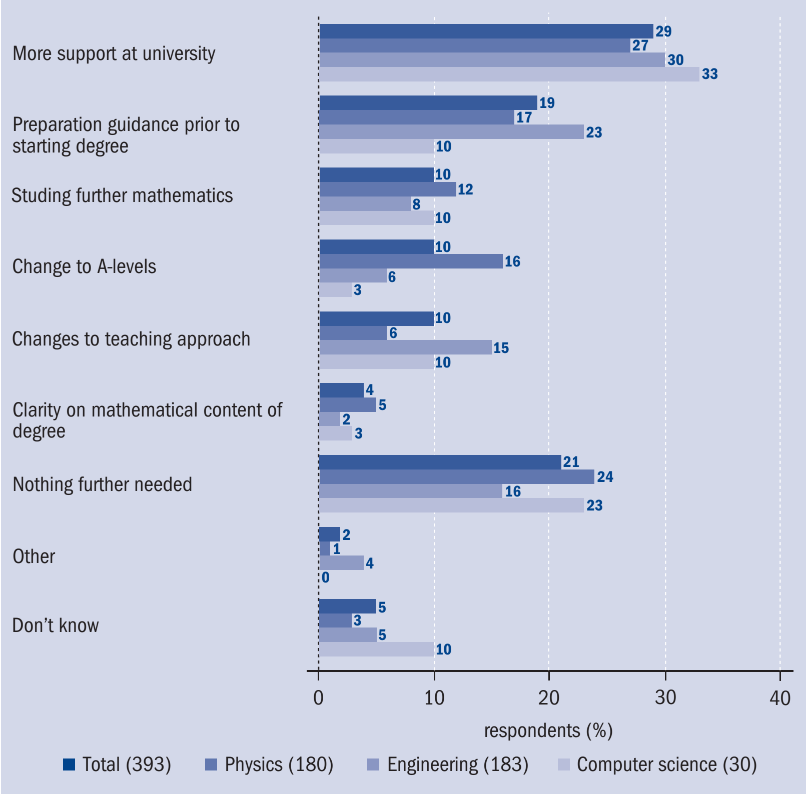
"Those who have taken further maths at A-level are fairly well prepared. It appears necessary to give those without this background a different introduction. It is not so much a question of mathematical ability but more using maths in a physics problem – reducing a physics problem to a maths problem that they can solve. We have tried workshops to address the latter (when to integrate, practise with vectors, forces and energy etc). Because of large classes (>150) these have been discontinued. However, they were extremely successful." **Academic**

There was a sense among academics that if students were to put in extra practice in mathematical techniques this would improve the situation and improve their mathematical fluency. This ties in with the earlier finding that those students who had taken advantage of self-help support being more likely to report that this had sufficiently addressed the issue.

"I have tried everything that I could think of, but only one thing worked. One year, I told the students that the 10 extra question booklets were mandatory, would be collected and checked. They would not pass the first year if they did not complete the booklets. The exam scores rose markedly that year. However, it was an enormous and thankless effort for me, and unsustainable with my other commitments. If students can elect not to engage in mathematics, most will not, to the detriment of their skills throughout the course." **Academic**

"If they were music students they would need to practise their scales. They just need more practice, until algebraic manipulations, powers, logs etc all come naturally and quickly to them. Then they can start to play the sonatas, concertos and symphonies that are physics." **Physics academic**

Figure 25: Further help to deal with mathematical content of degree



Base: all students (393).

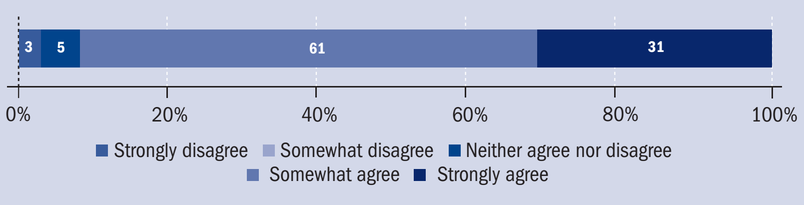
A further suggestion that was put forward by a small number of academics was to address the notion that mathematics teachers in schools cannot teach anything other than mathematics. While a teacher of one science can teach another (for example a chemist teaching physics), mathematicians are generally not allowed to cross over into teaching physics. It was suggested that due to the greater affinity between mathematics and physics compared to, for example, chemistry and physics, teaching provision should reflect this. Arranging teaching in this way could enable these teachers to highlight the crossover of skills of techniques, and allow for a more rounded skill set and better contextual knowledge.

5.8. Long-term impacts

5.8.1. Academics' perceptions of long-term impacts of lack of mathematical fluency

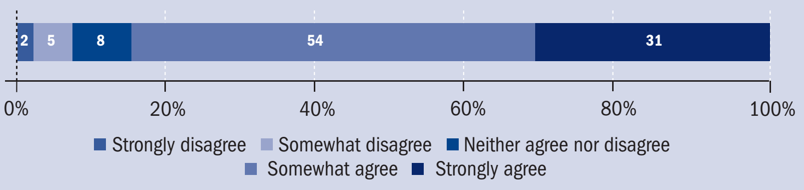
This section will explore the impacts, if any, that academics felt the perceived lack of fluency of some students may have on both their potential, and on

Figure 26: Extent to which lack of fluency in mathematics is an obstacle to students achieving their full potential in the long term



Base: all academics responding (40).

Figure 27: Extent to which agree that a lack of fluency in mathematics perceived to affect their department's ability to deliver an optimal programme of study



Base: all academics responding (40).

the ability of the university to deliver an optimal programme of study.

The academics were asked whether they have had to adapt the overall structure and/or content of their physics/engineering degree in light of incoming students' mathematical ability. Four-fifths (80%) of the academics said that they had. They were then asked to what extent they agreed that a lack of fluency in mathematics could be an obstacle to the students achieving their potential in the long term. Figure 26 shows the results.

A large proportion (92%) of academics surveyed agreed that a lack of fluency in mathematics was an obstacle to students achieving their full potential in the long term.

During the qualitative interviews, academics expanded on this by suggesting that this initial lack of fluency may impact on students' appetite for mathematics. Most manage to overcome the initial challenge, but some remain disadvantaged.

"I think there are a few who, in spite of all those measures, end up a little bit at sea mathematically. They're then hugely disadvantaged throughout the rest of the degree course, because of the style of lecturing, which, as I say, a lot of it is going through algebraic derivations. If they haven't really got to that level of fluency of understanding what somebody else is writing let alone writing it themselves, yes, they are at a serious disadvantage." **Physics academic**

One of the students interviewed also expressed thoughts around this:

"Before I came to university I was really confident with my mathematical ability. The first year I was good, but now the problems are getting more and more vast, hard and complicated. Sometimes I look at a problem and barely even attempt it because I just get it in mind that it's really difficult. Two years ago I would never have done that, so it's starting to get a bit more daunting."
Physics student

Academics were also asked to indicate to what extent they believed a lack of fluency in mathematics affected their departments' ability to deliver an optimal programme of study. Figure 27 shows the results.

More than four in five (85%) of academics agreed that a lack of fluency in mathematics among undergraduates affected their department's ability to deliver an optimal programme of study. These academics were asked to elaborate on the way(s) in which they felt the programme of study had been affected.

The responses focused around mathematical content having to be diluted, or introduced more slowly, which subsequently impacts on both the depth of understanding of students, and the amount of material/topics that can be covered throughout the course.

"Many topics previously studied by default in A-level seem now to be optional; material such as complex numbers cannot be assumed, and so courses must not run before we have 'levelled up' their knowledge." **Academic**

"Clearly if we could get all students to a more advanced level earlier it would be of benefit. Often a large amount of the first year is used to get everyone up to speed with predominantly A-level maths material (and some material that is no longer taught to most at A-level). This time could be spent introducing further concepts earlier that would be advantageous in other engineering ideas and material that relies on this maths."
Academic

Some of the specific areas that were being compromised/overlooked as a result were cited as quantum mechanics, theoretical physics, waves and electromagnetism.

A number of academics interviewed also talked of the strain placed on their department in having to focus too heavily on getting students' mathematics up to speed (by re-covering the A-level mathematics syllabus), and providing extra support, and the fact that this may not be sustainable in the long term.

"Out of a finite teaching budget, less time/resource will be expended on other teaching. Spending more time on re-covering the maths leads to less time spent on other topics, so you might worry that the rest of the course takes a hit." **Physics academic**

Further comments on resource suggested that in order to administer extra problem sheets, which most thought could be very beneficial, would require a high-level marking capacity, which is not always available or viable.

"I, personally, would like to see more marked work for credit in a way that doesn't massively drain the resources of the department. I mean, it's very labour intensive to mark every piece of work and give fantastic feedback on it. It will take us as long to mark each piece of work than the student to actually do it." **Physics academic**

5.9. Mathematics students' reasons for not studying physics

This section explores the results from the qualitative interviews conducted with mathematics students, who had the qualifications to study physics (or engineering) to degree level, but who chose not to.

5.9.1. Reasons for choosing A-levels

As observed with physics/engineering students, most of the mathematics students interviewed had chosen to pursue mathematics at A-level as they had always enjoyed it, and had an aptitude for it. As it is a core subject, and highly respected, it therefore seemed to go without saying that they would pursue it to A-level. Students also reported a significant degree of encouragement from teachers and parents.

"The maths was always a given. I always enjoyed it and was told by a teacher at school that I should do it." **Mathematics and physics student**

Physics was perceived to fit well with mathematics, especially for those who intended taking the mechanics module. This was therefore a key reason for many of the students to have chosen to pursue that at A-level also.

"I'm just good at it. I always enjoyed maths and physics was my favourite science. They kind of join together." **Mathematics student**

"I did maths because it was one of the few things I was really good at so I thought I might as well do it for A-level. [...] With physics, I never really planned to take it up but my physics teacher said I should." **Mathematics student**

5.9.2. Reasons for choosing a degree

Similarly to A-level choices, the majority of mathematics students had chosen their degree subject based on a life-long aptitude and passion for mathematics.

"I guess it's the only thing that truly made sense to me. I was good at it and the problem solving and satisfaction that you get from that made me more enthusiastic about it. It just seemed like the natural thing to want to study it further." **Mathematics student**

Those that were studying joint honours (mathematics and physics) were able to offer an interesting perspective as they were studying mathematics but also knew what a physics degree consisted of first-hand. These students felt that to study mathematics alone would be too "theoretical". They enjoyed the pure mathematics but relished the opportunity to be able to apply it, which they felt was not open to students taking "straight" mathematics.

Most students had discussed their degree options with a parent, teacher or careers adviser, primarily in terms of sounding out options that they had already considered. Much of the advice sought was around what careers various degrees might lead to.

"I spoke to my maths tutor and he was saying that with maths, because of the applications, you could use it in further maths. He even told me that in companies like Google, they have a lot of mathematicians making computer programmes and stuff so I thought it was a good course to go to." **Mathematics student**

5.9.3. Reasons for not choosing physics

Mathematics students were asked why they had chosen not to study physics to degree level, despite having the qualifications to do so.

There was a strong sense among these students that their desire to pursue a subject that involved problem solving pushed them towards mathematics rather than physics. Physics was perceived to involve more "learning" than straight problem solving, which was primarily driven by the nature or their experience of A-level physics.

"I like solving the mechanics in physics but I never really planned to do physics at university. It was quite interesting but some of the theoretical parts, you'd have to read a lot and I don't like reading, I'd prefer solving." **Mathematics student**

Again, the joint honours (mathematics and physics) students were able to offer a unique perspective on this issue: they didn't feel that physics A-level gave a clear indication of what physics is really like at degree level. They felt that it was a lot more mathematical than most A-level students appreciated.

"One of the problems is that physics A-level is totally unrelated. The maths content is brought out a bit but it doesn't give you a clear indication of what physics is if you did it further."
Mathematics and physics student

A mathematics student who had done a mathematics and physics foundation year prior to commencing their mathematics degree echoed this sentiment:

"The only time I associated maths and physics together was last year, not at all at A-level. I only really began to understand it in my foundation year but I had already chosen to do maths. If I could go back, I might think about studying it further if I had known what it involved but because I didn't, I didn't even think about studying it."
Mathematics student

An interesting point that was raised by one student was the idea that, for many students who had taken further mathematics, physics in comparison didn't seem as challenging, and so there was less of a pull towards studying to a higher level.

"Physics was one of the easiest A-levels. It was really interesting, but further maths was more challenging. Maybe if there were something further in physics I would have considered doing physics. When I started doing further maths I was in my second year of A-level and I realised that it was what I enjoyed the most. That's why I decided to go for maths." **Mathematics student**

Another reason that a relatively small number of students gave was around not having particularly good or inspiring physics teachers, which had put them off pursuing that subject to some extent.

Finally, a number of students indicated that a general lack of awareness of what would they could realistically do with a physics degree, beyond scientific research, had put them off studying it. Two of the mathematics and physics joint honours students went further and said that their peers who had been interested in pursuing physics perceived engineering to be the best choice.

"What you could do with a physics degree was never mentioned to me or gone over in my classes. I don't think it was ever mentioned. A lot of people who were interested in physics did engineering."
Mathematics and physics student

"People need to be shown a little bit more that they can do it because if you like that side of maths then why not do physics? It is maths anyway."
Mathematics student

6: Conclusions

6.1. Key themes

6.1.1. Contrasting student and academic perceptions

There was some degree of contrast between the students' and the academics' perceptions of students' ability to deal with the content of physics and engineering degree courses. While students expressed some initial surprise at the degree of mathematical content in their degree (their expectations were often based around the structure of A-level physics courses), most felt that they had adapted to the situation reasonably well.

Academics appeared slightly less positive about the students' ability to deal with what was being asked of them with regard to mathematics. This difference in opinion also extended to the perceived long-term impacts of the lack of fluency in mathematics among physics and engineering undergraduates; students did not report being worried that there would be any long-term impact on their future prospects with regard to issues with the mathematical content of their course. Academics, however, appeared more concerned that having had to go over content that they felt students should already have covered, meant missing out on teaching them some other more complex topics.

Academics did appear to have a good knowledge of their students' strengths and weaknesses, however, as responses to questions around elements that students find easy or struggle with, were very consistent across both samples.

6.1.2. Further mathematics

One of the key patterns to emerge from the research was that those students who had studied further mathematics to A- or AS-level standard reported coping better with the mathematical content of the degree, and as such perceived that they required less additional support (though this raised some concerns for academics, who suggested that this may lull them into a false sense of security). These students who had studied further mathematics also seemed slightly better prepared for the breadth of mathematical content, particularly during the first year of study. Many students and academics felt that studying further mathematics should therefore be made a requirement of studying physics or engineering at university.

6.1.3. Practice makes perfect

Another key finding was that one of the simplest ideas to help address the perceived lack of fluency in mathematics, from both the student and academic perspective, would be to ensure that students are able to practise their mathematics more – many academics compared this to the way in which a music student should practise their musical scales – so that mathematics becomes intuitive. Academics felt that this should be encouraged at A-level, rather than teaching mathematics "to exam", i.e. rather than teaching equations to be used "like recipes", instead putting them in context and allowing students to understand where they have come from, and what using them actually means. The idea was that students would then be better placed to understand the application of mathematical techniques and concepts in a physics/engineering context. Academics and students also felt that more practice would be beneficial at university, via problem sheets and tutorials, though many students felt that they were too time-poor for this to be viable. Academics suggested that a solution could be to make practice sheets compulsory, but feared that enforcing this could put unsustainable strain on resource in their departments.

6.1.4. Compartmentalisation

Academics perceived a lack of crossover between mathematics and physics at A-level, which was felt to not only leave students unprepared for the amount of mathematics in physics, but also led to them not applying their mathematical knowledge to their learning of physics and engineering. It was felt that this crossover should be highlighted, both to encourage those that enjoy mathematics to pursue physics, but also to ensure that students are able to link the two fields of thinking together.

6.1.5. Reasons for not studying physics

This "compartmentalisation" was also seen to be a contributing factor to students that were qualified to study physics at university choosing not to. Many students reported being unaware that physics contained so much mathematics, perceiving it to involve more "learning" than "problem solving", a love of and aptitude for which was what had pushed them towards pursuing mathematics to degree level. It was felt by students that the mathematical and problem-solving nature of degree-level physics should be made clearer, so that students could make a more informed choice.

There was also felt to be a lack of knowledge around what a physics degree could lead into, career-wise. Many of the mathematics students interviewed felt that mathematics gave them broader options than physics post-graduation.

Cover image courtesy of Prof. Sir Michael Berry
Computer simulation of the bow wave of a ship. The V shape arises from focusing, and the pattern decorating it involves the same mathematics as the rainbow, which is also a kind of focusing – of light waves rather than water waves.

Mind the Gap

Mathematics and the transition from A-levels to physics and engineering degrees

A report prepared for the Institute of Physics by EdComs

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