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Improving Outcomes on a Foundation Mathematics Module to Complement Progression onto Science Degrees

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The use of mathematical concepts is fundamental for students embarking on science degree programmes. However, it has become increasingly apparent that many students are not sufficiently equipped with the mathematical skills required. This is likely to be due to several factors relating to degree entry requirements, prior mathematical education and the level of enjoyment of mathematics. This study discusses the outcomes of redesigning a foundation mathematics module to focus on the scientific application of mathematical concepts and therefore prepare learners for progression onto their chosen science degree. The new mathematics module has learner outcomes that are more in line with the outcomes of other content-driven science modules on the foundation year course because of the significantly enhanced achievements of the home students entering the foundation course with level 2 mathematics and a break from mathematics study of two or more years.

Introduction

Science undergraduates are required to demonstrate competence in a range of mathematical skills, such as identifying relationships between variables, preparing solutions and carrying out dilutions, operating laboratory equipment and analysing data. As a consequence, there has been much discussion around the importance of the role of mathematics within science degrees (e.g. May, 2004), the perceptions and anxieties of students regarding mathematics (e.g. Dobson, 2018; Escalera-Chavez et al., 2017; Palmer, 2009; Wachsmuth et al., 2017), whether prospective students should study A-level maths prior to their degree (Adkins & Noyes, 2018), for science degree courses to consider revising the entry requirements to include A-level maths, and in some cases further maths (Darlington & Bowyer, 2016), and the role and impact of integrating maths within the degree programme (Matthews et al., 2009; Speth et al., 2010).

The Foundation Science course at the University of Nottingham is targeted at learners who do not have the necessary pre-requisite science qualifications needed for direct access onto their chosen science degree course. The course consists of three content-based modules

covering chemistry, biology and mathematics, and a fourth module, 'Studying Science', which focuses on the academic skills needed to be a successful scientist. The overall aim of the Foundation Science course is to enable learners to develop knowledge and understanding to a level which is comparable to that of direct entry students and prepare them for undergraduate science study. The course is delivered at a fast pace and, in order to prepare students for the wide range of progression pathways, it provides broad coverage of diverse content. The inclusion of the maths module is an important element of the foundation course as, although most learners gained grade B or higher in GCSE maths or a level 2 equivalent qualification, the majority have not studied maths for two or more years. The maths module should therefore provide the opportunity for learners to re-engage with maths, develop confidence in using maths and illustrate the application of maths within the science disciplines.

The original mathematics provision for science foundation students was led through the School of Mathematical Sciences (SoM), comprising one two-hour lecture, delivered by a mathematics specialist, and one one-hour workshop, delivered by the foundation science team within the School of Life Sciences (SoLS) each week. The module content was developed by the SoM and aimed not only at the science foundation students but also at other first year undergraduate students requiring maths skills for their degree programmes. The workshop provided within SoLS allowed some elements of the maths content to be applied to scientific examples but the time for this was limited and workshops and lectures were often not always directly aligned.

Analysis of the attainment data on the science foundation programme for cohorts entering the programme from 2014 – 2017 showed a significant gap between the achievement on the mathematics module and the other science modules for chemistry and biology, with the pass rates and average marks on the mathematics module consistently lower (Figure 1). During the mathematics workshops, students with level 2 qualifications, or those returning to education with no recent mathematical experience, struggled with the application of basic mathematical concepts, such as algebra and fractions, to scientific problems and were often overwhelmed by many of the level 3 concepts being introduced – for example calculus – from a mathematical perspective. Due to time and timetabling constraints, there were also limited opportunities to develop understanding and application to relevant science examples.

Foundation Mathematics Module Development

In response to an anecdotal lack of student engagement and relatively poor student performance in the module delivered by the School of Mathematical Sciences, the maths module was brought in-house at the start of the 2018 academic year and delivered by a member of the Foundation Science team within the School of Life Sciences. When reviewing the previous programme of study, only a small proportion of content was deemed unnecessary at foundation level as it was not directly applicable to basic maths applications in science. Furthermore, the learning objectives were in line with both level 2 (GCSE or equivalent) and level 3 (A-level or equivalent) mathematics programmes and the QAA benchmark statements regarding maths knowledge required for science-based degrees. Nevertheless, there was a need to re-focus the content of the module so that it better enabled Foundation Science students to view mathematical concepts from the perspective of a scientist as the 'end user' of mathematical tools. Hence the main topics were divided into the four sections of numbers and algebra, graphing and linearization, basic calculus and statistics. The delivery of these topics aims to provide a transition between levels 2 and 3 while enabling students to better understand how key principles of mathematics can be used in scientific contexts. Bringing the module in-house

also provided a clear link between the lectures and practical workshops where students can practice the concepts met.

Attainment Analysis

Foundation Cohort Comparison

Overall module marks were compared to assess whether there were any cohort-level differences between attainment in the content-based foundation modules and the overall course. Descriptive statistics for the five cohorts suggest that there is very little variation across the year groups (Table 1).

Further inferential statistical tests were carried out to see if there were any significant differences in achievement between the cohorts. Shapiro-Wilks normality tests identified that some of the data sets displayed non-normal distributions and to account for the non-normality of these data sets non-parametric Kruskal-Wallis tests were used for the comparisons of attainment across the cohorts. The Kruskal-Wallis test resulted in all p-values > 0.05 for each content-driven module and the overall course outcomes, suggesting no statistically significant differences at the cohort level across the programme.

Foundation Module Comparison within Cohorts

As the cohort data suggest no statistically significant difference between the overall module marks between cohorts (Table 1) the distribution of marks within each cohort was investigated. Figure 1 illustrates the pass rates and average modules marks for each of the content-based modules of biological sciences, chemistry and maths. The data from 2014 – 2017 illustrate the differences observed in the pass rates and average module marks that led to the module being brought in-house for delivery from the scientific perspective.

During the first year of implementing the new module (2017 – 18), there was a large increase in both the average attendance and the pass rate of the maths module that brought the module in line with the other content-based modules, and the average module mark for maths was also comparable to the average module mark in chemistry. There is no obvious improvement with the 2018 – 19 cohort although the drop in the maths pass rate from 2017 – 18 is accompanied by a reduction in both the attendance and pass rates of the other modules. However, the average module mark for maths in this cohort is again comparable to that of the chemistry module, which was not the case with the previous maths module delivered between 2014 – 2017. Also, the maths pass rate for 2018-19 is still higher than the 2014 – 15 cohort, which has higher pass rates and average marks in both the chemistry and biology modules. It should also be noted that for the three years of available attendance data there is some suggestion of a potential link between attendance and higher pass rates in the maths module.

The difference between the overall programme mark and the subject module mark for each student was calculated and the average value for each cohort is illustrated in Figure 2. The maths differences for the previous SoM module (2014 – 2017) are on average more negative than the overall module mark with differences greater than both the chemistry and biological sciences modules. For the current SoLS maths module (2017 – 2019), the differences are still more negative, but are comparable with the chemistry module.

Data set	Cohort	N	Mean	SD	Min	Max	Shapiro-Wilks *p*-value*	Kruskal-Wallis *p*-value†
Overall % foundation course	2014-15	24	60.0	10.8	35.3	79.4	0.275	0.673
	2015-16	34	58.7	13.0	18.2	92.1	0.061	
	2016-17	46	57.4	14.0	12.6	88.1	0.122	
	2017-18	38	59.9	14.1	37.0	84.5	0.180	
	2018-19	33	55.5	12.8	30.2	84.5	0.932	
Overall % module mark Biological Sciences	2014-15	24	63.3	12.8	36.0	88.0	0.844	0.185
	2015-16	34	65.0	13.7	21.0	87.0	0.020	
	2016-17	46	59.9	11.9	15.0	83.0	0.003	
	2017-18	38	63.2	14.3	37.0	87.0	0.148	
	2018-19	33	60.1	11.5	36.6	81.0	0.736	
Overall % module mark Chemistry	2014-15	24	58.9	13.4	24.1	85.7	0.791	0.147
	2015-16	34	59.1	15.4	17.0	94.3	0.688	
	2016-17	46	57.7	17.7	10.3	87.5	0.233	
	2017-18	38	55.8	16.4	21.7	87.3	0.778	
	2018-19	33	50.6	15.6	1	84.8	0.863	
Overall % module mark Mathematics	2014-15	24	47.0	20.6	18.0	86.0	0.225	0.089
	2015-16	34	42.7	23.7	3.0	98.0	0.166	
	2016-17	46	52.2	23.7	11.0	94.0	0.051	
	2017-18	38	57.0	19.2	11.9	93.7	0.326	
	2018-19	33	50.1	19.5	15.5	94.0	0.310	

Table 1: Descriptive statistics and Kruskal-Wallis analysis of the overall foundation module marks for biological sciences, chemistry and mathematics.
*The test rejects the hypothesis of normality when the *p*-value is less than or equal to 0.05. As some of the data reject the hypothesis of normality, non-parametric tests have been used for comparison purposes.
†A *p*-value < 0.05 means that the distribution of marks is significantly different across the cohorts.

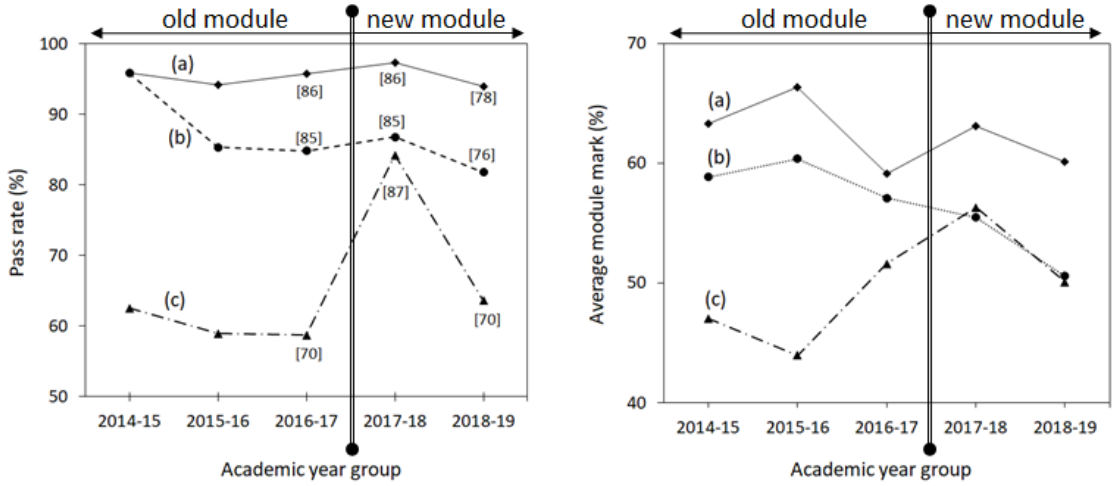

Figure 1: The variation of pass rate (left panel) and average module mark (right panel) with academic year for the foundation modules of (a) biological sciences, (b) chemistry, and (c) mathematics. The numbers in brackets on the left panel for the last three cohorts represent the average percentage attendance for each of the modules (these data were not available for the 2014-15 and 2015-16 cohorts).

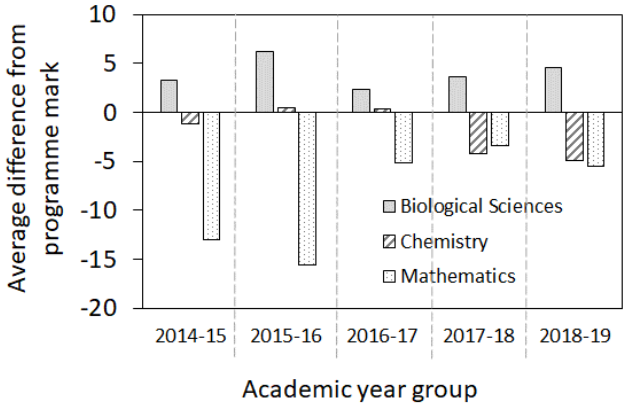

Figure 2: The average difference in module mark from the overall programme mark for each cohort.

Impact of Implementing the New Mathematics Module

The foundation course has traditionally comprised a mixture of home (H), EU and overseas (OS) students. While most home students have only level 2 qualifications in maths and have not studied maths for 2 years, most EU and OS students have had some maths in their Level 3 studies. Although prior qualification data are not always available, informal discussions with OS and EU students indicate that most of these students had been actively engaged with maths study prior to starting on the foundation course and had not had a significant break from maths. Therefore, the attainment data was separated into the categories of home students with level 2 qualifications in maths (HL2, n = 94), and the rest of the students, which comprises overseas (OS, n = 50), EU (n = 20) and home students with level 3 qualifications in maths (HL3, n = 11).

Inspection of Figure 3 indicates that the observed improved pass rates in the maths module for the 2017 – 2019 cohorts can be attributed to the improved attainment of home students with level 2 maths (HL2). The pass rates associated with the OS, EU and HL3 students

are in line with the other module (chemistry and biological sciences) pass rates before and after implementing the maths module changes.

The distribution of marks for the maths module obtained by both student categories before (2014 – 2017) and after (2017 – 2019) the maths module changes are illustrated in Figure 4. A comparison of the spread of data before and after the maths module changes was carried out for each student category. Shapiro-Wilks normality tests were carried out on the attainment data collected to identify the most suitable inferential statistical analysis between the groups being compared (Tables 2 and 3). To account for the non-normality of some of the distributions of attainment data, nonparametric Mann-Whitney U tests were carried out for comparison of the attainment of the two different groups. Where significant differences are determined the effect size, η^2 (Lenard and Lenard, 2016), is also presented to provide an indication of the importance of any differences.

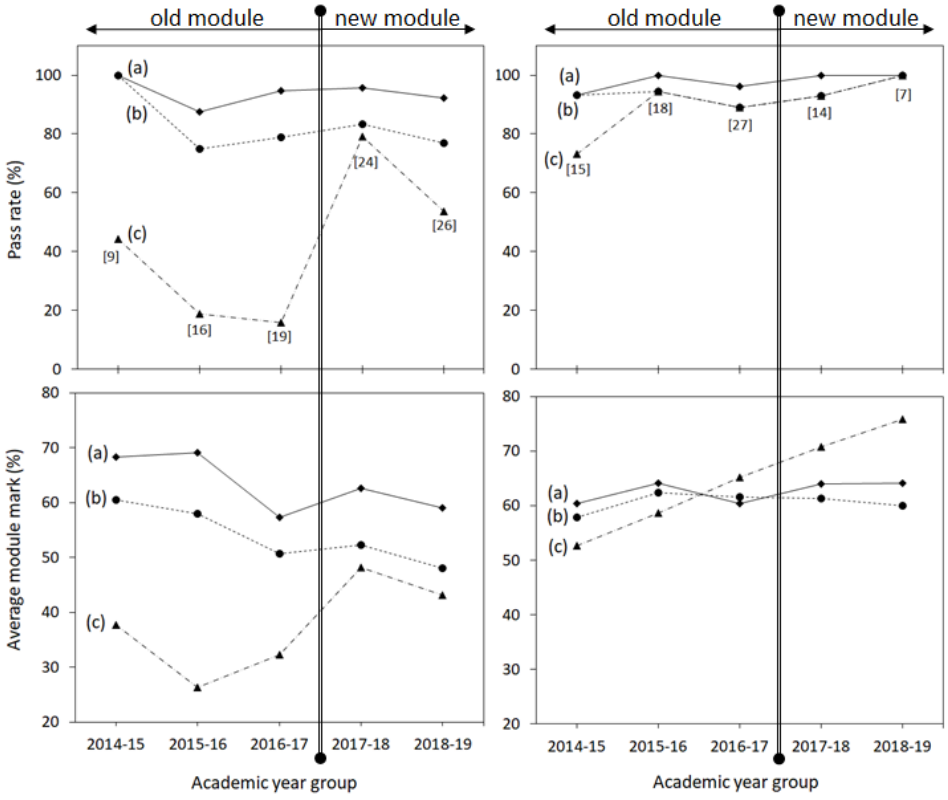

Figure 3: Variation with academic year of pass rate for HL2 students (top left) and OS/EU/HL3 students (top right), and average module mark for HL2 students (bottom left) and OS/EU/HL3 students (bottom right), for (a) biological sciences, (b) chemistry, and (c) mathematics modules. The numbers in brackets in the top panels represent the number of students for each of the categories identified in each year group.

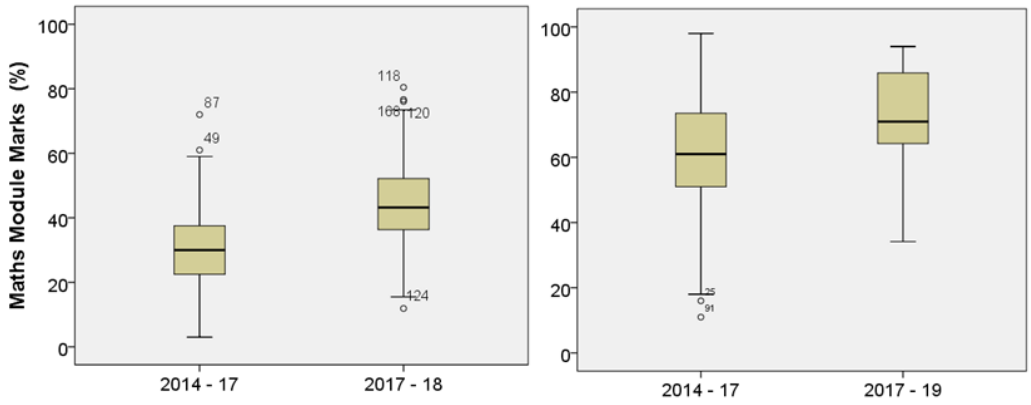

Figure 4: Box plots illustrating the spread of marks for HL2 students (left panel) and OSEUHL3 students (right panel) during 2014 – 2017 (before the module changes) and 2017 – 2018 (after the module changes).
Note: The error bars show the full range of marks not including any identified outliers, indicated by numbered points. Lower outliers are defined as being lower than Q1 – 1.5 x IQR and upper outliers are defined as being greater than Q3 + 1.5 x IQR, where Q1 and Q3 are the 1st and 3rd quartiles and IQR is the interquartile range.

Statistical analysis of the HL2 category of student suggests that there is no significant difference in the chemistry, biological sciences and overall foundation programme average marks as all *p*-value > 0.05 (Table 2). The analysis does, however, suggest a significant difference in the attainment of the HL2 students before and after implementation of the new maths module (*p*-value = 0.000) with an effect size of 0.212, indicating a large impact in the 'zone of desired effects' for effective learning (after Hattie 2009).

Data set (HL2 students only)	**Group**	**Shapiro-Wilks *p*-value***	**Mann-Whitney U *p*-value†**	**Effect size, η^2**
Overall % foundation course	2014-17	0.042	0.679	-
	2017-19	0.732		
Overall % module mark Biological Sciences	2014-17	0.046	0.180	-
	2017-19	0.514		
Overall % module mark Chemistry	2014-17	0.166	0.076	-
	2017-19	0.862		
Overall % module mark Mathematics	2014-17	0.330	0.000	0.212‡
	2017-19	0.126		

Table 2: Mann-Whitney U analysis of module marks comparing HL2 students separated into categories of before (2014 – 2017, n = 43) and after (2017 – 2018, n = 51) the maths module changes.
*The test rejects the hypothesis of normality when the *p*-value is less than or equal to 0.05.
†*p*-values < 0.05 means that the distribution of marks is significantly different across the categories.
‡Effect sizes greater than 0.140 are interpreted as being a large effect as defined by Cohen (1988) and in the zone of desired effects as defined by Hattie (2009) (Lenard and Lenard, 2016).

Data set (OS/EU/HL3 students)	Group	Shapiro-Wilks *p*-value*	Mann-Whitney U *p*-value†	Effect size, η^2
Overall % foundation course	2014-17	0.012	0.351	-
	2017-19	0.391		
Overall % module mark Biological Sciences	2014-17	0.007	0.593	-
	2017-19	0.716		
Overall % module mark Chemistry	2014-17	0.161	0.838	-
	2017-19	0.565		
Overall % module mark Mathematics	2014-17	0.067	0.010	0.083‡
	2017-19	0.301		

Table 3: Mann-Whitney U analysis of module marks comparing OS/EU/HL3 students separated into categories of before (2014 – 2017, n = 60) and after (2017 – 2018, n = 21) the maths module changes.
*The test rejects the hypothesis of normality when the *p*-value is less than or equal to 0.05.
†*p*-values < 0.05 means that the distribution of marks is significantly different across the categories.
‡Effect sizes between 0.06 and 0.10 are interpreted as being an intermediate effect as defined by Cohen (1988) and in the zone of desired effects as defined by Hattie (2009) (Lenard and Lenard, 2016)

Statistical analysis of the OS/EU/HL3 category of student again suggests that there are no significant differences in the chemistry, biological sciences and overall foundation programme average marks as all *p*-value > 0.05 (Table 3). The analysis does, however, suggest a significant difference in the attainment of the OS/EU/HL3 students before and after implementation of the new maths module (*p*-value = 0.010) with an effect size of 0.083, indicating an intermediate impact 'zone of desired effects' for effective learning after Hattie (2009). Although the analysis does suggest a positive impact for this category of student, the effect size is smaller than the impact on the HL2 category of student.

Areas of Greatest Impact

To identify where students have benefitted the most from the maths module changes, attainment data was separated into grade categories of good pass (>55%), pass (40 – 55%), soft fail (30 – 40%) and hard fail (<30%). A good pass was defined by the mark required in the chemistry and biological sciences modules for progression onto most of the science degree programmes from the foundation course.

Figure 4 shows the breakdown of the percentage of students achieving each of the grade categories prior to and after the maths module changes. The profiles obtained from including all students shows a reduction in the percentage of hard fails after the maths module changes. These hard fails have been redistributed into the soft fail and pass categories; there is little impact on the good pass category. The largest change is observed in the HL2 category of students, where most students are in the soft fail and hard fail grade categories prior to the maths module changes, and there is a shift from the hard fail and soft fail categories into the *pass* and *good pass* categories. For the OS/EU/HL3 students, the main change tends to be an increase in the percentage of students gaining a good pass with fewer hard and soft fails after the maths module changes.

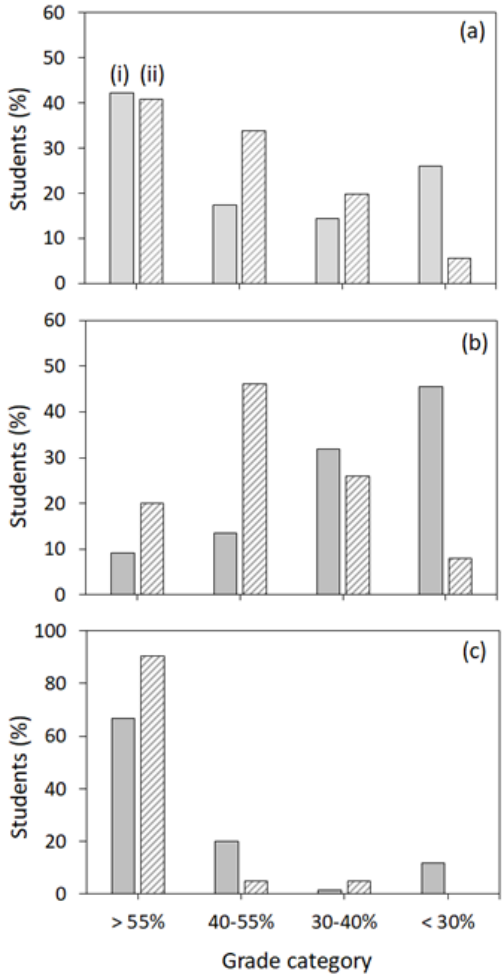

Figure 4: Percentage of students achieving each grade category for the maths module during (i) 2014 – 2017 (before the module changes) and (ii) 2017 – 2019 (after the module changes). (a) All students taking the module, (b) HL2 students only, and (c) OS/EU/HL3 students only.

Learner Feedback for the Mathematics Module

Module feedback is currently only available from the 2017-18 cohort. These students were aware that it was the first year of the new module and were asked to comment on their experience of it and whether they had A-level maths prior to starting the foundation course. Student responses indicate that they felt they had benefitted from having maths concepts linked to their scientific applications. They were also able to identify the future benefits of studying maths in an applied context. Example responses include:

> Did maths A-level, so found it reasonably easy but I found it interesting to learn why we do things such as differentiation/integration the way we do.

> From an A-level background the module is straightforward. Having a scientist as a lecturer was really good as [the lecturer] was able to go through the questions and understand some of the challenges we would face.

> I found it both interesting and valuable. Maths refresher useful for life as well as course.
>
> The module has given me more confidence in Maths and helped [that] the skills learnt in the lectures [were] able to be used in the other modules.
>
> I have covered some of the topics in the past. The A-level topics. I believe that the questions with science application has helped me to combine the skills learnt at A-level with real scientific problems as I wasn't able to do that before.
>
> I found this module very challenging, but I have learned concepts that I know will be invaluable later on.
>
> This module has provided me with the math skill set needed to become a scientist. Although, I have encountered many topics from the module, I didn't encounter their application till now.

Conclusions

Observations had indicated that there was a difference in the pass rates associated with the foundation maths module compared to the other content-driven science modules on the foundation year course. From these observations, it was decided to bring the maths module 'in-house' and to focus on the scientific application of the mathematical concepts that are used in a variety of science disciplines. Although there is no significant difference between the five cohorts of students in terms of average module marks and course marks, the analysis of maths modules attainment data provides some evidence that students experiencing the School of Life Sciences maths module (2017 – 2019), compared to the School of Mathematical Sciences module (2014 – 2017), have levels of attainment that are more in line with those of the other content-based modules of chemistry and biological sciences. The main contributing factor to the improved outcomes is the positive impact that the changes in the maths module, notably the scientific focus of the maths concepts, have had in enhancing the grade profile of the home students with level 2 maths qualifications who have experienced a gap of two years or more in maths study (HL2). For this student group, the number of hard fails has been reduced and there has been an increase in results in the soft fail and pass categories.

From the limited feedback received, it is apparent that the students identified clear links between the maths concepts being taught, their scientific application and their use in the other Foundation Science modules. Therefore, the initial steps of bringing the module in-house and having a scientist deliver the content seem to have had a positive impact. However, there are still a number of students who struggle with, and consequently fail the module, and therefore further development of learning activities is needed to improve student confidence, help students gain a better understanding of the key concepts involved, and to further reduce the percentage of fails in this module.

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