RESEARCH ARTICLE

Investigating students' perception of the importance of calculus: a cross-discipline comparison to inform module development

Joseph D. Bailey, Department of Mathematical Sciences, University of Essex, Colchester, Essex, UK. Email: jbailef@essex.ac.uk (contact author)
Jessica Claridge, Department of Mathematical Sciences, University of Essex, Colchester, Essex, UK. Email: jessica.claridge@essex.ac.uk
Alexander Partner, Department of Mathematical Sciences, University of Essex, Colchester, Essex, UK. Email: akpart@essex.ac.uk

Abstract

This study compares perceptions of calculus across disciplines in university education. As highlighted by Rasmussen et al. (2014) more evidence is needed to understand the "relationship between calculus and the client disciplines of engineering, physics, biology, and chemistry", with calculus courses often designed from the perspective of mathematicians. This work aims to provide insight as to when it is appropriate to group different disciplines together for taught calculus modules in Higher Education (HE).

This short study assesses how students perceive the importance of calculus across disciplines including Mathematics, Electronic Engineering, Economics and Business.

Specifically, we consider the following:

1) Are there differences in how students from different disciplines perceive the importance of studying calculus?

2) Do students view the field of calculus as: something to be learned to pass their course; something to be fully understood; or a tool for future study/career?

Whilst this small study cannot provide definitive answers to these open yet important questions, the work presented here does reveal that students in Mathematics and Economics had mostly similar and positive perceptions about calculus. In contrast, however, Business students often viewed calculus differently when compared to the other disciplines. Therefore, these results suggest some potential groupings for teaching cross-discipline- calculus. Importantly, they also suggest how further research should develop regarding how such groupings could affect attainment, pass rates and other pedagogical considerations noted in HE calculus modules.

Keywords: calculus, undergraduate, mathematics, cross-disciplinary, student perception.

1. Introduction

Calculus education underpins many undergraduate programmes including Mathematics, Engineering, Computer Science, Economics and Business Studies (Hagman et al, 2017). As such, it can be used to serve multiple purposes; from being a foundation for preparing students for later modules, to being a benchmark indicating the level of mathematical ability required for the discipline being studied (Hagman, 2019). This, along with the volume of topics covered under the banner of *calculus*, means that such courses will often contain a large amount of content which can exacerbate or create negative feelings within students towards the STEM field as a whole (Hagman et al, 2017). This can lead to calculus modules being linked with various challenges within Higher Education (HE) such as STEM degree drop-out rates (Rasmussen & Ellis, 2013; Leu, 2017), failure or underachievement in degree courses (Eng et al., 2010) and under-preparation for future professional careers (Hensel & Hamrick, 2012). As such, it is necessary to carefully consider the teaching environment, including how to group students from different disciplines in order to increasing students' perceptions of the importance of calculus., This, in turn, could help to reduce the above-mentioned challenges which are specific to calculus and allow for their underlying causes to be better explored.

Due to calculus' ubiquity across many STEM disciplines, it is often the subject which is used to trial new or alternative teaching styles and learning environments. These include flipped-learning classes (Sahin et al., 2015), the use of virtual environments (Bognar et al., 2010) and other technological setups and inclusions (Tall et al., 2008; Kay & Kletskin, 2012; Sevimli, 2016) as well as educational initiatives such as peer teaching (Weulander et al., 2016) and self-regulation (Johns, 2020). However, there is little existing research which has demonstrated how students engage with calculus itself, especially given that students tend to be taught in broadly the same manner with similar content regardless of their field of study (Czocher et al., 2013). Hence, there is a need to explore and understand how calculus relates to the separate disciplines in order to identify specific content that is the most beneficial for students and, therefore, develop individual curricula which reflect the needs and interests of different programs. This should increase students' interest and engagement with the content itself, with the added benefit of exploring different teaching approaches (Rasmussen et al., 2014; Hitt & González-Martín, 2016).

Understanding how students view the usefulness of learned material is necessary since perceived difficulty and importance can be the most significant factor of a student's behaviour (Ting & Lee, 2012) and academic success (Harackiewicz et al., 2016). Students' perceptions of the importance of a topic can vary depending on many factors including: the learning environment (Ahmed et al., 2018; Yoo & Kim, 2019); their preconceived notions of the topic (Ferreira & Santoso, 2008); the module structure (Tudor et al., 2010); and the use of relevant assignments (Fedesco et al. 2017). It is known that to increase perceived importance of a subject one needs to develop problem solving skills and increase attainment, as well as incorporate applicable examples of mathematical concepts which are relevant to one's field of study (Marrongelle, 2001; Osman et al., 2013; Willmot & Simms, 2018). Therefore, understanding the motivation and key areas of importance for different disciplines allows educators to tailor module content to their students. However, calculus cohorts are often treated uniformly with little analysis on the subtleties in perception and motivation across different disciplines which clearly identifies a research gap that needs addressing (Hitt & González-Martín, 2016; Rasmussen et al., 2014).

When designing modules, disciplines may be grouped together without careful consideration for the differences in learning styles and motivations. For instance, different disciplines may have different overall aims for learning a module, varying from fully understanding the underlying theory, to simply providing a mechanism to cope with later modules. It is common for first year university students who intend to study a range of STEM and quantitative degrees to study the same calculus module, a practice that is common across the world in HE such as Scotland (Kinnear, 2018), America (Rasmussen & Ellis, 2013), Brazil (Maderia et al., 2019) and Malaysia (Tang et al., 2013). This is often the case as it is assumed that since the underlying content needs to be taught in various degree schemes, students can be taught together to minimise teaching strain within departments. However, differences in learning styles across disciplines studying calculus have been noted (Alamolhodaei, 1996; Dündar, 2015; Johns, 2020), implying some combinations may be more appropriate than others. Indeed, groupings can be inconsistent even within the same university institution. For example, the University of Essex will teach calculus content to Economics and Business students together in a foundation year (Year 0), whereas Economics and Mathematics students will be taught calculus content together in Year 1. Which leads to the question; which, if any, such groupings are appropriate when teaching across disciplines?

Here, by using a simple survey study, we look at how students perceive the importance and relevance of calculus depending on their degree scheme. The aim is to provide evidence of similarities or dissimilarities that can lead to more appropriate module groupings, minimising repeated taught courses across HE institutions whilst ensuring that students are taught in the manner most beneficial for their discipline's requirements.

2. Research Questions

We consider the following open and important questions:

1) Are there differences in how students from different disciplines perceive the importance of studying calculus?

2) Do students view the field of calculus as: something to be learned to pass their course; something to be fully understood; or a necessary and useful tool for their future study and/or career? Does this vary by discipline, by gender, by progression through HE?

We aim to give an initial indication of disciplines which may be appropriate to group together for teaching according to students' differing interests and perceptions. We hypothesised that Mathematics students would see the direct relevance of calculus to their degree scheme and therefore understand the need to study the underlying principles. By contrast, we hypothesised that students of Economics, Business Studies and Engineering will perceive calculus as a tool or a set of rules to be used to answer applied problems i.e., less interest in understanding why the techniques work and little concern about how all the methods from across calculus are linked together.

3. Materials and Methods

This study was approved by the ethics committee of the University of Essex (ETH1920-1755). As an incentive, participants were automatically entered into a prize draw to win a £20 Amazon voucher upon successful completion of the survey.

3.1 Participants

Participants were recruited based on whether they had studied a first-year module that incorporates calculus content, in their respective departments of either; Mathematical Sciences (M), Electronic Engineering (EE), Business (B) or Economics (Ec) at the University of Essex. The modules studied were: MA101 - Calculus; CE142 - Mathematics for Engineers; BE300 - Quantitative Methods & Finance; and EC115 - Methods of Economic Analysis.

A total of 145 responses were used in the analysis; the demographic breakdown is given in Table 1. Of these, the largest set of respondents had studied the Business module (n=57) with a similar number taking the Mathematics (n=34) and Economics module (n=33) and fewer taking the Electronic Engineering module (n=21). These reflect the comparative sizes of the departments. The responses were a majority male (n=86) with first year students having the highest number of responses (n=68), compared to second year/year abroad students (n=45) and final year students (n=33). In general, the small sample size can raise methodological concerns, however, our numbers are comparable to other similar studies (Newton & McCunn, 2015; Darmaji et al., 2019; Ballantine & Larres, 2004).

Table 1: Demographic characteristics of the study population.

Discipline	Total responses	Gender				Year of Study (current)			
		Male	Female	Other	Prefer not to say	1st	2nd	Final	Placement/ Year Abroad
M	34	*19*	*15*	*0*	*0*	*13*	*12*	*9*	*0*
B	57	*35*	*22*	*0*	*0*	*29*	*13*	*11*	*4*
Ec	33	*15*	*17*	*0*	*1*	*13*	*9*	*10*	*1*
EE	21	*17*	*2*	*1*	*1*	*12*	*6*	*3*	*0*
Total	**145**	***86***	***56***	***1***	***2***	***67***	***40***	***33***	***5***

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE).

3.2 Materials

Participants were asked to complete some initial demographic questions followed by 16 items that assessed their perception of calculus using statements and a 5-point Likert scale (*1=strongly disagree, 5=strongly agree*). Participants were also asked to complete a multiple-choice question asking them to select the sentence which most described their opinion of studying calculus. The questions used in this study are given in Table S1 in Appendix A. Questions were designed to give insight into the perceived importance of calculus and its role within the larger context of the degree and work prospects. To ensure clarity and consistency, students were instructed to use the definition of *calculus* as:

> *Calculus only includes topics such as differentiation, integration, algebraic manipulation, sequences and series, trigonometric functions, vectors, complex numbers. This does not include any probability, statistics nor financial content.*

3.3 Procedure and Experiment

The survey was compiled in Qualtrics (https://www.qualtrics.com). All qualifying students from the chosen departments were emailed with details about the study that included a link to the survey which they were invited to complete in July 2020. The survey was available for one week after participants had completed their end of year examinations after which time the survey was closed and the link was disabled. Students were advised that responses would be kept anonymous but may be linked to group-level outcomes and used in publication or further research.

3.4 Data Analysis

Descriptive statistics for each question were found by analysing the mean composite score for each Likert scale question (Boone & Boone, 2012; Kale, et al. 2015). Significant differences between responses were calculated using Mann-Whitney-Wilcoxon tests (Sullivan & Artino, 2013). All analysis was performed using R (R Core Team, 2020).

4. Results

Table 2: Means and standard deviations of the responses to the items in the calculus questionnaire described in Table S1.

Item	Mean				S.D.			
	M	B	Ec	EE	M	B	Ec	EE
1^	2.03†	2.88*	2.15	2.57	0.953	1.019	0.906*	1.248†
2^	1.97	2.70*	2.09	1.71†	0.999	1.149	1.182†	0.956*
3	3.71	3.82†	3.67*	3.76	1.00	1.037	0.990*	1.221†
4^	1.79†	2.79*	2.00	2.62	1.122*	1.292	1.270	1.465†
5	4.44†	3.53*	4.31	3.81	0.959	1.136	0.78*	1.250†
6	4.29†	3.18*	3.94	3.71	0.938	1.269	0.914*	1.419†
7	3.03	2.98	3.09†	2.81*	1.058	1.009*	1.088	1.209†
8	4.44†	3.47*	3.84	3.50	0.894*	1.197	1.036	1.395†
9	4.26†	3.70*	4.03	3.70	0.864*	1.195	1.016	1.380†
10	3.94†	3.49*	3.84	3.50	1.043*	1.151	1.068	1.504†
11	4.27†	3.37*	4.10	3.45	0.674*	1.080	0.978	1.468†
12^	2.58*	3.21†	2.68	2.80	0.867*	0.940	1.166	1.322†
13	4.03†	3.26	3.55	2.75*	0.951*	1.188	1.060	1.209†
14	3.84†	3.16	3.52	2.85*	0.939*	1.099†	1.061	1.089
15	3.64†	3.49	3.52	3.25*	1.270*	1.297	1.313	1.517†
16	3.27†	3.11	2.94*	3.15	0.977	0.859*	1.031	1.268†

*Mean and standard deviation values that are denoted with † and * symbols indicate the highest and smallest values, respectively, for each item. Items that are denoted with a ^ symbol indicate items which were negatively coded and so the symbols for the highest and lowest values are also reversed for ease of interpretation.*

Mathematics students gave the strongest opinions with the highest mean score for 12 questions, along with the lowest standard deviation for 10 questions, indicating that their responses were the most aligned at the intradisciplinary level (Table 2). Whereas, Electronic Engineering students had the widest range of answers, demonstrated by having the highest standard deviation in 14 questions.

When making comparisons between disciplines, Mathematics and Business were seen to differ the most with significant differences in responses in nine items (Q1, Q2, Q6, Q8, Q9, Q11, Q12, Q13, Q14; Table 3 & Table S4). Business and Economics had significant differences in two items (Q1, Q6), whereas, Mathematics and Economics had no significant differences. Four items were significantly different between Mathematics and Electronic Engineering (Q8, Q11, Q13, Q14), one item was significantly different between Business and Electronic Engineering (Q2), and no significant differences were found between Economics and Electronic Engineering (Table 3 & Table S4).

Only five items (Q3, Q7, Q10, Q15, Q16) were answered similarly by all disciplines (Table 3). Q3 and Q7 explored whether students believed they needed to repeat methods and techniques to succeed in calculus rather than concentrate on the underlying principles; with which the majority of students agreed. Q15 asked about the novelty of the calculus content in the course and returned the most varied responses for all disciplines across all items (demonstrated by having the highest standard deviation for each discipline [Table 2]). Q1 asked if students thought of calculus as many disconnected topics, this was answered broadly by Electronic Engineering and Business students, however, both Mathematics and Economic students strongly disagreed (Table 2 & Table S3). Although Q16, which asked if the contents of the taught module covered many seemingly separate topics compared to other taught modules, was generally agreed with by all disciplines demonstrated by all means being above 2.5 (Table 1), all disciplines included many responses who disagreed with this statement (Tables S2 & S3). Interestingly apart from Q3, these items (Q7, Q10, Q15, Q16) all had relatively flat distributions, with responses not highly skewed towards any answer indicating that there was a wide range of opinions across the students.

Table 3: The pairings of disciplines where there was a significant difference in the responses (indicated by Mann-Whitney test $p<0.05$) for each item in the calculus questionnaire described in Table S1. The statistical values for each test can be found in Table S5.

Item	Pairings of disciplines with a significant difference in responses			
1	M-B	B-Ec		
2	M-B		B-EE	
6	M-B	B-Ec		
8	M-B			M-EE
9	M-B			
11	M-B			M-EE
12	M-B			
13	M-B			M-EE
14	M-B			M-EE

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE). Where an item is not listed then no pairings of disciplines had significant differences for that item.

When asked about their agreement with studying calculus as being necessary for their future career (Q10), the responses displayed qualitatively different results between the disciplines despite their similar mean values (Table S3). Whilst, on average, all disciplines indicated that they perceived calculus as necessary for their career, it was noticeable that a substantial proportion of Business (21%) and Electronic Engineering (30%) students disagreed (Table S2 & S3). In comparison, disciplines agreed studying calculus was beneficial to performing well in their degree (Q9; Table 2) though still a notable proportion of students from Business and Electronic Engineering disagreeing with the statement (24.6% and 20.0% respectively; Table S3).The statement *there is only one correct way to solve a calculus problem* (Q2), exhibited a high proportion of Business students with strong agreement, resulting in a mean of 2.70 (Table 1). This was the only item where one discipline gave an average response different to the other three disciplines; the other disciplines generally disagreed with the statement. Interestingly, however, 14% of Mathematics students still showed agreement with the statement.

Disciplines differed over the connection of calculus and their degree, with students from Business and Electronic Engineering generally not seeing the connection at the beginning of studying their modules (Q4; $mean_B = 2.80$, $mean_{EE} = 2.60$; Table 2), whereas Mathematics and Economics did see the connection at the outset ($mean_M = 1.80$, $mean_{Ec} = 2.00$; Table 2). Upon completion of their respective modules all disciplines tended to agree there was a connection (Q5), however, there was still a high proportion of Business (21%) and EE (19%) students who did not consider there to be a connection (Table S3). All disciplines claimed to have enjoyed studying calculus as part of their degree (Q17) with over 60% selecting either sentence 1 or 3 (Table 4). The most selected answer stated that students both 'enjoyed' and found the topic 'useful'. However, this was most pronounced for Mathematics (87%) and Economics (67.7%) with under half of respondents selecting this sentence for Business (45.6%) and Electronic Engineering (40%). Over a third of Business and EE students intimated that studying calculus was not useful for their degree (Q8) which was similar to the results asking if calculus is useful to study in their subject (Q5). Although, of those Business students who did not consider calculus useful, a larger proportion (21%) enjoyed it, compared to those who did not (12%) (Q17; Table 4).

Table 4: Number of participants which picked the given sentence which best described their opinion of studying calculus.

Descriptive sentence	M	B	Ec	EE	Total
I enjoyed studying calculus and the module was useful for my degree.	27 (82%)	26 (46%)	21 (68%)	8 (40%)	82 (58%)
Although I don't enjoy calculus the module was useful for my degree.	3 (9%)	12 (21%)	9 (29%)	4 (20%)	28 (20%)
I enjoyed studying calculus but the module was not very useful for my degree.	2 (6%)	12 (21%)	1 (3%)	4 (20%)	19 (13%)
I don't enjoy calculus and the module was not very useful for my degree.	1 (3%)	7 (12%)	0 (0%)	4 (20%)	12 (9%)

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE). The values in brackets show the proportion of each discipline which selected the given sentence.

Business students had the highest proportion of students expecting to go onto a specific career post university (B-65%; M-37%; Ec-52%; EE-52%; Table 5) compared to going into further study (B-18%; M-26%; Ec-33%; EE-33%; Table 5). Mathematics students were the least sure of their postgraduate development with almost a third of students stating that they were undecided, which was double the proportion of both Business and Economics students (Table 5). Although it should be highlighted that Business had a slim majority of respondents who were in their first ear (51%; Table S4).

Table 5: Future plans of participants after finishing their undergraduate studies for each discipline. This question was asked to all participants regardless of their current year of study.

Next Plans	M	B	Ec	EE	Total
Employment	13 (37.1%)	37 (64.9%)	17 (51.5%)	11 (52.4%)	78 (53.4%)
Further study	9 (25.7%)	10 (17.5%)	11 (33.3%)	7 (33.3%)	37 (25.3%)
Undecided	11 (31.4%)	9 (15.8%)	5 (15.2%)	2 (9.5%)	27 (18.5%)
Other	2 (5.7%)	1 (1.8%)	0 (0%)	1 (4.8%)	4 (2.7%)

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE). The values in brackets show the proportion of each discipline who selected the given option.

5. Discussion

Calculus is at the core of many aspects of mathematical education. Students from distinct disciplines have differing perceptions of the usefulness and importance of the subject depending on how they identify links to their specific field. Therefore, teaching certain cohorts in an identical manner might be detrimental for how a student engages with the content. However, identifying similarities may allow HE institutions to optimise the effectiveness of their teaching by efficiently grouping students according to disciplines which share similar perceptions of the subject. In this simple study we considered how students studying a variety of quantitative degrees perceived calculus and, importantly, how they felt it affected their studies and future careers. This is a vital yet largely unexplored question in the literature (Hitt & González-Martín, 2016; Rasmussen et al., 2014).

Our results indicate that students from different disciplines do have marked differences in their perception of calculus and its importance for their studies, however there are also notable similarities observed (Table 1; Table S5). Economics and Mathematics have similar perceptions about calculus, including: the usefulness of studying it for their degree and future career, the need to understand the underlying principles, and how calculus relates to other aspects of their studies. In contrast, Business students were seen to have more varied responses, with many questions answered differently compared with other disciplines. Interestingly, Electronic Engineering responses placed them closer to Economics rather than Mathematics; however, this could in part be due to the smaller number of responses. Electronic Engineering were also most divided in their responses (shown by having the highest standard deviation in 14 questions), indicating that these students have a wide range of perceptions of calculus.

Business students were the only discipline to largely agree that there is only one way to solve calculus questions (Q2). This is supported by Q1 and Q3 where Business students felt they only needed to memorize methods to successfully answer questions and that calculus was formed of many disconnected topics. These findings potentially indicate that Business students view calculus as a collection of methods for solving unconnected problems rather than one coherent topic. Business students were also the respondents with the highest proportion expecting to go onto a specific career post university, potentially explaining why they were more focused on applications than underlying theory. These results support the idea of including exercises and examples based around the core concepts of calculus with clear applications in settings with which Business students will be familiar (Marrongelle, 2001; Osman et al., 2013; Willmot & Simms, 2018).

For both Mathematics and Economics students, the majority indicated that they enjoyed the study of calculus and found it useful. They also shared an agreement that calculus was connected to their degree and did not see calculus as many disconnected topics. These results would suggest that these students share a similar perception of mathematics: namely that they view the underlying theory as important as well as valuing a comprehensive understanding in the concepts. Given these similarities, Mathematics and Economics may be a suitable grouping for joint teaching of calculus, thus allowing for cross-disciplinary study which has been shown to be beneficial across age ranges (Kokotovich, 2008; Vahey et al. 2012).

There are many ways that this work could be expanded upon in future research. For example, whilst these views reflect the opinions of the students, they do not demonstrate the thoughts of those teaching it. It is reasonable to conject that the student views of a subject are affected by the way in which a teacher presents the ideas, which in turn may be influenced by the teacher's own perceptions. Interestingly, this has been shown not to be the case in environmental biology in secondary school students (Kiarie, 2016), where there was found to be no statistically significant relation between teachers and students' perception and attainment in the subject. However, enthusiasm in teaching is known to be positively correlated to an increase attainment in mathematics and STEM subjects in secondary education (Kunter et al., 2008; Lazarides et al., 2018; Jungert et al., 2020) as well as in subjects in HE (Entwistle et al., 2002; Devlin & O'Shea, 2012).

Understanding calculus education is a complex issue which goes beyond simply identifying differences and similarities when stratified by discipline. It is always hard to make precise conclusions about students' perceptions and outcomes due to the complex array of attributing factors, however, these results do indicate some tentative results which could be used in cross-discipline module design. Previous work has highlighted the effect various attributing factors can have on the performance of students studying calculus including gender (Ellis et al, 2016), ethnicity (Riegle-Crumb & Grodsky, 2010; Minor, 2016), and socio-economic background (Byun et al, 2015). A larger study looking to combine these factors together with the teaching environment, including groupings and student/staff perceptions of the importance of calculus, would allow for a more in-depth analysis of attainment, pass rate and value added.

Our results did not indicate any major differences when considering the additional factors of gender, year of study or future plans (see Appendix C for further information). However, a natural extension of this work would be to consider these factors in a mixed effect model, to determine if subgroups within disciplines have differing perceptions. This could also be used to identify what, if any, of these factors are the driving force behind the similarities and dissimilarities found to exist between groups. Such work would require a larger set of respondents to ensure a more even distribution amongst all combinations of factors (such as discipline, gender, year of study and future plans).

In conclusion, in this small study we find some tentative evidence to support cross-teaching in calculus, with certain groupings more effective than others, such as Mathematics and Economics compared with Mathematics and Business. These results can be used to inform module design to optimise teaching environments, thus allowing for the factors causing the observed challenges in calculus such as relatively low attainment, STEM degree drop-out rates and under preparation for future careers to be better understood, analysed and addressed.

6. Copyright

The anonymised data used in this study is available upon request from the authors.

7. Appendices

Appendix A - Questionnaire

Table S1: Tests and questionnaires items.

Demographic questions

1. Which degree course are/were you studying towards? (e.g Mathematics, Data Science and Analytics, Maths with Finance)

2. Which year of study have you just completed? (Oct 2019 - Jun 2020; excluding any Foundation or Repeated years)
   (1st; 2nd; Placement/Year Abroad; Final)

3. Which of the following modules have you taken most recently?
   (MA101 – Calculus; BE300 – Quantitative Methods & Finance; CE142 – Mathematics for Engineers; EC115 – Methods of Economic Analysis; None of the above)

4. What age are you?
   (18-22; 23-25; 26+; Prefer not to answer)

5. To which gender do you most identify?
   (Female; Male; Other; Prefer not to answer)

6. Did you study post-16 education in England, Wales or Northern Ireland?
   (Yes; No)

7. Did you study a mathematics or statistics qualification between the ages of 16-18?
   (Yes; No)

8. Which of the following post-16 qualifications have you studied? Select all that apply.
   (AS-/A-Level Mathematics; AS-/A-Level Further Mathematics; AS-/A-Level Statistics; IB Mathematics SL/HL; IB Further Mathematics HL; Level 3 Core Maths; None of the above)

9. Did you study a foundation year at XXX?
   (Yes; No)

10. Which of the following module(s) did you study in your foundation year?
    (IA112 – Essential Mathematics; IA115 – Mathematical Methods and Statistics; IA124 – Mathematics and Statistics; None of the above)

11. What are your plans immediately following your degree?
    (Further study; Employment; Undecided; Other - please specify below)

Items in the calculus questionnaire

For the remainder of the questionnaire the term 'calculus' refers to specific content of [selected module]. This only includes topics such as differentiation, integration, algebraic manipulation, sequences and series, trigonometric functions, vectors, complex numbers. This does not include any probability, statistics nor financial content.

You will now be shown a series of statements that will require you to reflect on your perceptions of the calculus content of [selected module]. For each statement, please select the option that indicates to which you agree with each statement. *(1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree)*

Please note that these questions refer only to the *content* of the module. They are <u>not</u> designed to comment on the lecturer, lecturing style or module material.

1. I think of calculus as many disconnected topics.
2. There is only one correct way to solve a calculus problem.
3. In order to solve problems in calculus, you need to memorize many different methods and techniques.
4. At the time of studying [selected module] I did not consider there to be a connection between calculus and my degree scheme.
5. Having completed [selected module] I consider there to be a connection between calculus and my degree scheme.
6. Outside of [selected module], I often came across questions in my studies which required knowledge of calculus.
7. In order to succeed in my degree, I mostly needed to repeat problems and techniques used in calculus, I do/did not need to learn the underlying principles.
8. It is necessary to study calculus to: - study my subject.
9. It is necessary to study calculus to: - get a high mark in my subject.
10. It is necessary to study calculus to: - do well in my anticipated field of work.
11. I think that the calculus component of [selected module] was important for my overall understanding of the contents of my degree.
12. The subject of calculus has little relation to what I will experience in the outside world.
13. The calculus content of [selected module] increased my interest in: - mathematics.
14. The calculus content of [selected module] increased my interest in: - my subject.
15. The majority of the calculus contents of [selected module] was either new to me or involved a deeper learning of topics I had previously studied.
16. The calculus contents of [selected module] included a large number of separate topics compared to my other modules.

Final question regarding perception of calculus

Select the sentence which is most applicable for you:

1. I enjoyed studying calculus and the module was useful for my degree.
2. Although I don't enjoy calculus the module was useful for my degree.
3. I enjoyed studying calculus but the module was not very useful for my degree.
4. I don't enjoy calculus and the module was not very useful for my degree.

Appendix B – Additional Tables

Table S2: Mean, standard deviation and the number of participants for the responses to each item in the calculus questionnaire in Table S1.

Item	Mean	S.D.	Disagree or strongly disagree	Neither agree nor disagree	Agree or strongly agree
1	2.47	1.07	79 (54.1%)	40 (27.4%)	27 (18.5%)
2	2.24	1.15	101 (69.2%)	13 (8.9%)	32 (21.9%)
3	3.75	1.03	21 (14.4%)	19 (13%)	106 (72.6%)
4	2.35	1.33	92 (63.4%)	15 (10.3%)	38 (26.2%)
5	3.96	1.1	19 (13.1%)	16 (11%)	110 (75.9%)
6	3.69	1.22	29 (20%)	20 (13.8%)	96 (66.2%)
7	2.99	1.06	54 (37.2%)	37 (25.5%)	54 (37.2%)
8	3.79	1.18	23 (16.1%)	18 (12.6%)	102 (71.3%)
9	3.91	1.12	17 (11.9%)	25 (17.5%)	101 (70.6%)
10	3.68	1.16	25 (17.5%)	31 (21.7%)	87 (60.8%)
11	3.75	1.1	26 (18.3%)	16 (11.3%)	100 (70.4%)
12	2.89	1.06	52 (36.6%)	44 (31%)	46 (32.4%)
13	3.44	1.17	32 (22.5%)	30 (21.1%)	80 (56.3%)
14	3.36	1.09	30 (21.1%)	42 (29.6%)	70 (49.3%)
15	3.5	1.31	42 (29.6%)	19 (13.4%)	81 (57%)
16	3.12	0.98	39 (27.5%)	48 (33.8%)	55 (38.7%)

The percentages in brackets show the proportion of the entire study population who gave the given response.

Table S3: Proportion of each discipline for each item's responses in the calculus questionnaire in Table S1.

Item	Disagree or strongly disagree				Neither agree nor disagree				Agree or strongly agree			
	M	B	Ec	EE	M	B	Ec	EE	M	B	Ec	EE
1^	71.4%	38.6%	63.6%	52.4%	20.0%	33.3%	30.3%	19.0%	8.6%	28.1%	6.1%	28.6%
2^	82.9%	52.6%	72.7%	85.7%	2.9%	14.0%	9.1%	4.8%	14.3%	33.3%	18.2%	9.5%
3	14.3%	12.3%	15.2%	19.0%	14.3%	10.5%	15.2%	14.3%	71.4%	77.2%	69.7%	66.7%
4^	77.1%	52.6%	78.1%	47.6%	8.6%	10.5%	3.1%	23.8%	14.3%	36.8%	18.8%	28.6%
5	5.7%	21.1%	3.1%	19.0%	5.7%	14.0%	9.4%	14.3%	88.6%	64.9%	87.5%	66.7%
6	5.7%	35.1%	9.4%	19.0%	5.7%	17.5%	15.6%	14.3%	88.6%	47.4%	75.0%	66.7%
7	37.1%	33.3%	34.4%	52.4%	25.7%	31.6%	21.9%	14.3%	37.1%	35.1%	43.8%	33.3%
8	5.7%	24.6%	9.7%	20.0%	0.0%	15.8%	12.9%	25.0%	94.3%	59.6%	77.4%	55.0%
9	2.9%	17.5%	3.2%	25.0%	8.6%	21.1%	29.0%	5.0%	88.6%	61.4%	67.7%	70.0%
10	8.6%	22.8%	9.7%	30.0%	20.0%	24.6%	25.8%	10.0%	71.4%	52.6%	64.5%	60.0%
11	2.9%	28.1%	9.7%	30.0%	5.9%	14.0%	12.9%	10.0%	91.2%	57.9%	77.4%	60.0%
12^	47.1%	21.1%	45.2%	50.0%	35.3%	35.1%	25.8%	20.0%	17.6%	43.9%	29.0%	30.0%
13	5.9%	26.3%	19.4%	45.0%	14.7%	22.8%	29.0%	15.0%	79.4%	50.9%	51.6%	40.0%
14	2.9%	26.3%	19.4%	40.0%	32.4%	31.6%	22.6%	30.0%	64.7%	42.1%	58.1%	30.0%
15	26.5%	28.1%	29.0%	40.0%	11.8%	15.8%	12.9%	10.0%	61.8%	56.1%	58.1%	50.0%
16	20.6%	26.3%	32.3%	35.0%	35.3%	36.8%	35.5%	20.0%	44.1%	36.8%	32.3%	45.0%

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE). Items that are denoted with a ^ symbol indicate items which were negatively coded.

Table S4: Number of participants by year of study and discipline.

Year of Study	M	B	Ec	EE	Total
1st	14 (40%)	29 (50.9%)	13 (39.4%)	12 (57.1%)	68 (46.6%)
2nd	12 (34.3%)	13 (22.8%)	9 (27.3%)	6 (28.6%)	40 (27.4%)
Final	9 (25.7%)	11 (19.3%)	10 (30.3%)	3 (14.3%)	33 (22.6%)
Placement/Year Abroad	0 (0%)	4 (7%)	1 (3%)	0 (0%)	5 (3.4%)

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE). The percentages in brackets show the proportion of each discipline who gave the given response.

Table S5: Results of the Mann-Whitney-Wilcoxon test for similarities between responses for each item in the calculus questionnaire shown in Table S1 when comparing between pairs of disciplines.

Item	M-B		M-Ec		M-EE		B-Ec		B-EE		Ec-EE	
	W-stat	***p-value***	**W-stat**	***p-value***	**W-stat**	***p-value***	**W-stat**	***p-value***	**W-stat**	***p-value***	**W-stat**	***p-value***
1	642.5*	*0.002**	540.5	*0.586*	282.5	*0.093*	1237*	*0.007**	656	*0.493*	281.5	*0.193*
2	706.5*	*0.006**	523.5	*0.364*	379.5	*0.760*	1134	*0.064*	798*	*0.009**	391.5	*0.276*
3	942.5	*0.563*	587.5	*0.884*	387.5	*0.684*	1008.5	*0.459*	663	*0.346*	359.5	*0.787*
4	736.5	*0.015*	559	*0.993*	262.5	*0.035*	1137	*0.025*	603	*0.960*	245.5	*0.050*
5	1237.5	*0.012*	564	*0.938*	449	*0.048*	692	*0.016*	586	*0.872*	410.5	*0.057*
6	1418.5	*<0.001*	634	*0.167*	449	*0.048*	625*	*0.006**	473	*0.120*	369.5	*0.448*
7	986.5	*0.929*	527	*0.663*	411.5	*0.429*	865.5	*0.676*	679.5	*0.334*	393	*0.268*
8	1334*	*0.001**	630	*0.061*	482.5*	*0.001**	712	*0.075*	579.5	*0.906*	380	*0.101*
9	1277.5*	*0.004**	652.5	*0.048*	422	*0.062*	788.5	*0.333*	546	*0.749*	325	*0.732*
10	1209.5	*0.052*	578.5	*0.578*	408	*0.225*	747.5	*0.184*	557	*0.872*	345	*0.439*
11	1303.5*	*0.001**	600.5	*0.126*	451*	*0.005**	691	*0.047*	566	*0.963*	373	*0.132*
12	627*	*0.003**	487	*0.576*	326	*0.793*	1106.5	*0.039*	725	*0.056*	319	*0.859*
13	1270*	*0.004**	679.5	*0.017*	493.5*	*0.001**	848.5	*0.742*	668	*0.219*	377.5	*0.163*
14	1261.5*	*0.009**	591.5	*0.330*	499*	*0.002**	744	*0.189*	666	*0.238*	407	*0.045*
15	1015	*0.672*	546.5	*0.775*	387	*0.345*	875	*0.937*	625	*0.480*	342	*0.496*
16	1056	*0.448*	611	*0.243*	365	*0.638*	946.5	*0.562*	567	*0.975*	289	*0.674*

Disciplines specified as Mathematics (M), Business (B), Economics (Ec), Electronic Engineering (EE).

Appendix C – Additional Analyses

Here we include the results of responses when grouped by gender (Male, Female), year of study (1st, 2nd or Final year) and future plans (employment, Further Education, undecided). These analyses were ancillary to the main aim of the work in which differences by discipline studied was the major concern.

In each case, visual inspection does not reveal any appreciable differences (see Figs S1-S3), certainly when compared with the results isolated by discipline (Fig S4). However, to fully examine the combined effect of these factors, an inter-/intra- analysis would be required. Here we note that to get robust results a larger data set with more evenly dispersed participants from all combinations of subcategories would be required (e.g., here Electronic Engineering had only two Female respondents compared to 17 Male; Table 1).

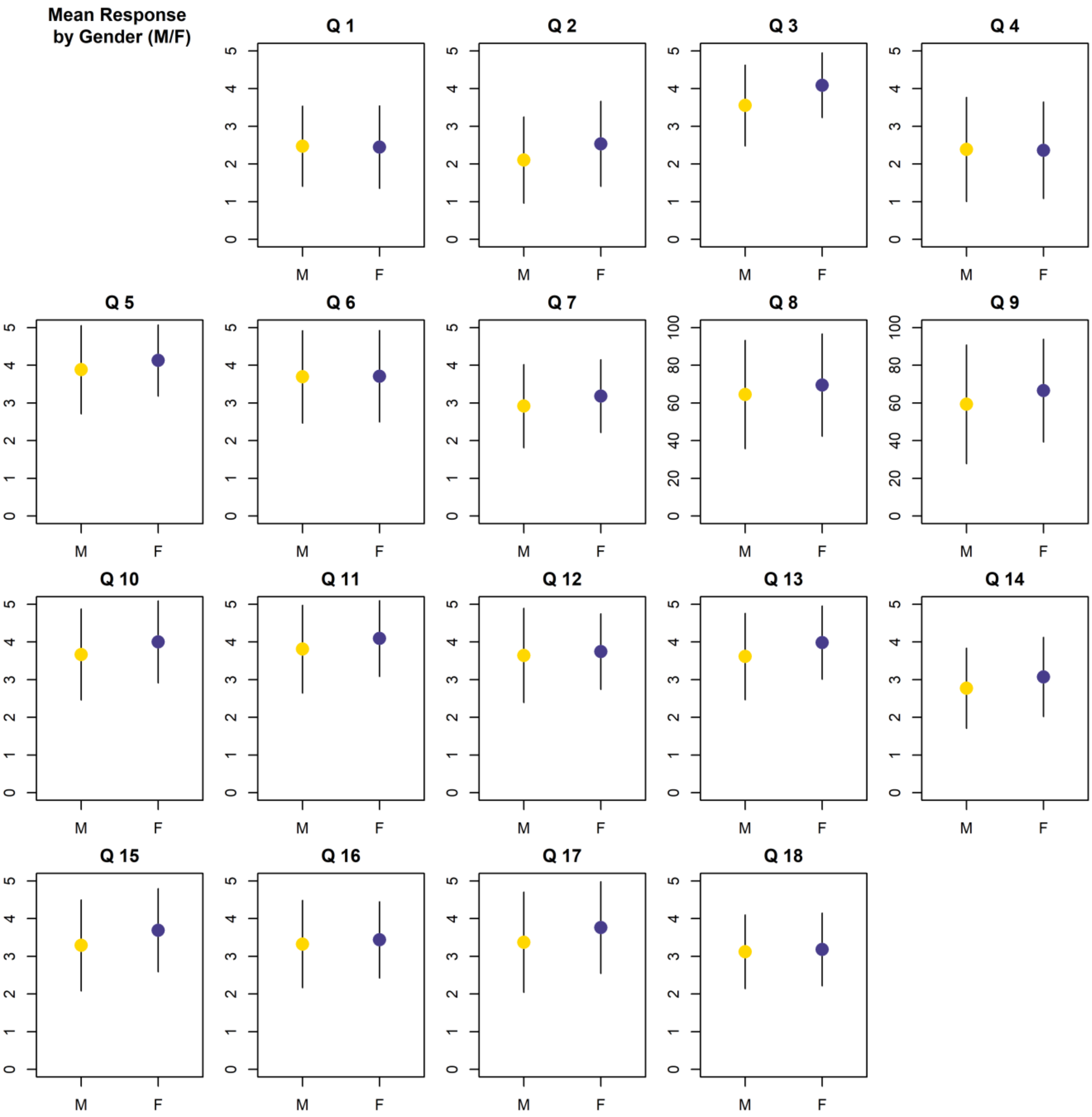

Figure S 1. Panel showing the mean response for each question by gender (Male – yellow circle; Female – purple circle). Bars depict s.d.

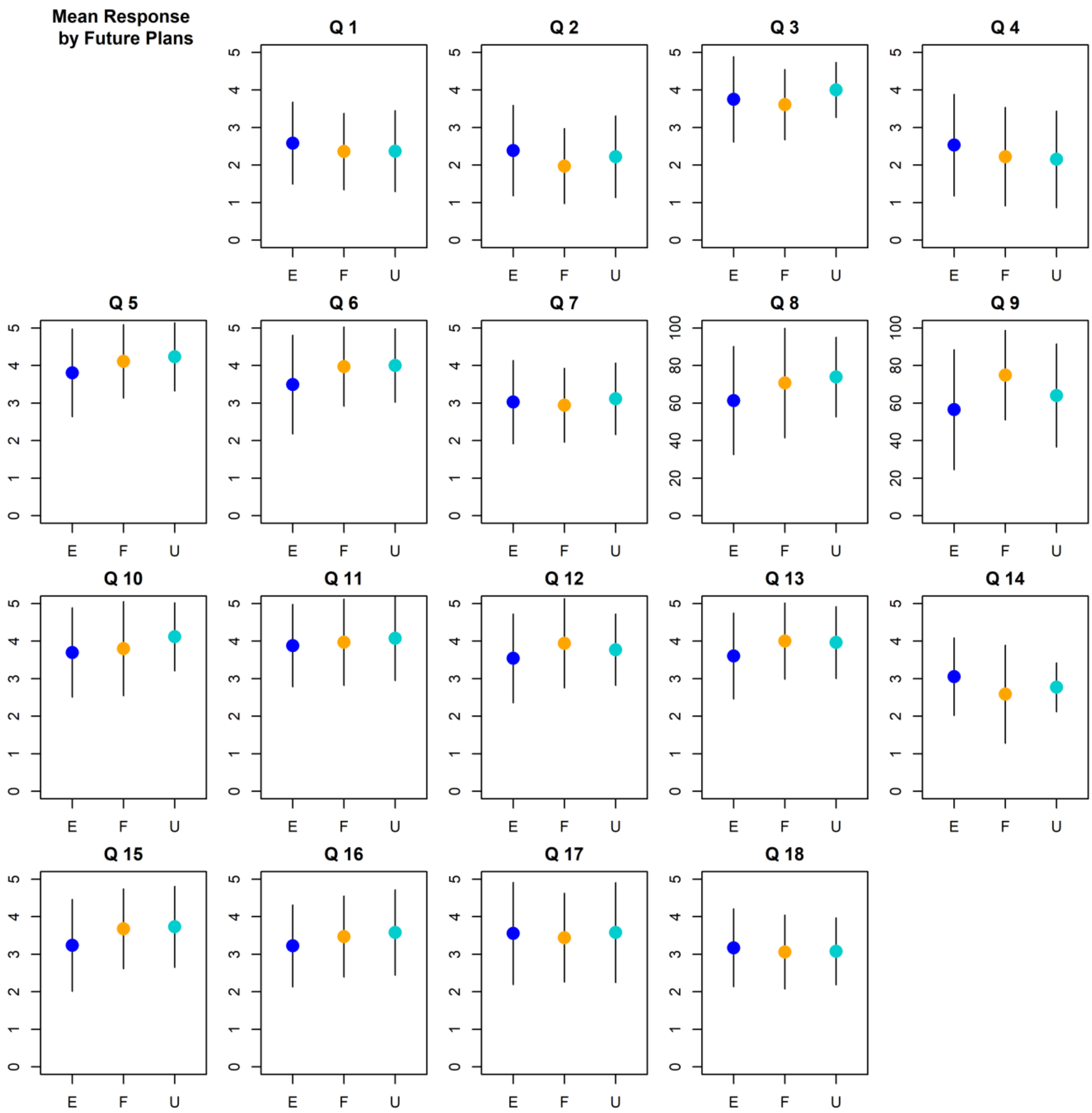

Figure S 2. Panel showing the mean response for each question by future plans ('E' – Employment, dark blue circle; 'F' – Further Education, orange circle; 'U' – undecided, cyan circle.). Bars depict s.d.

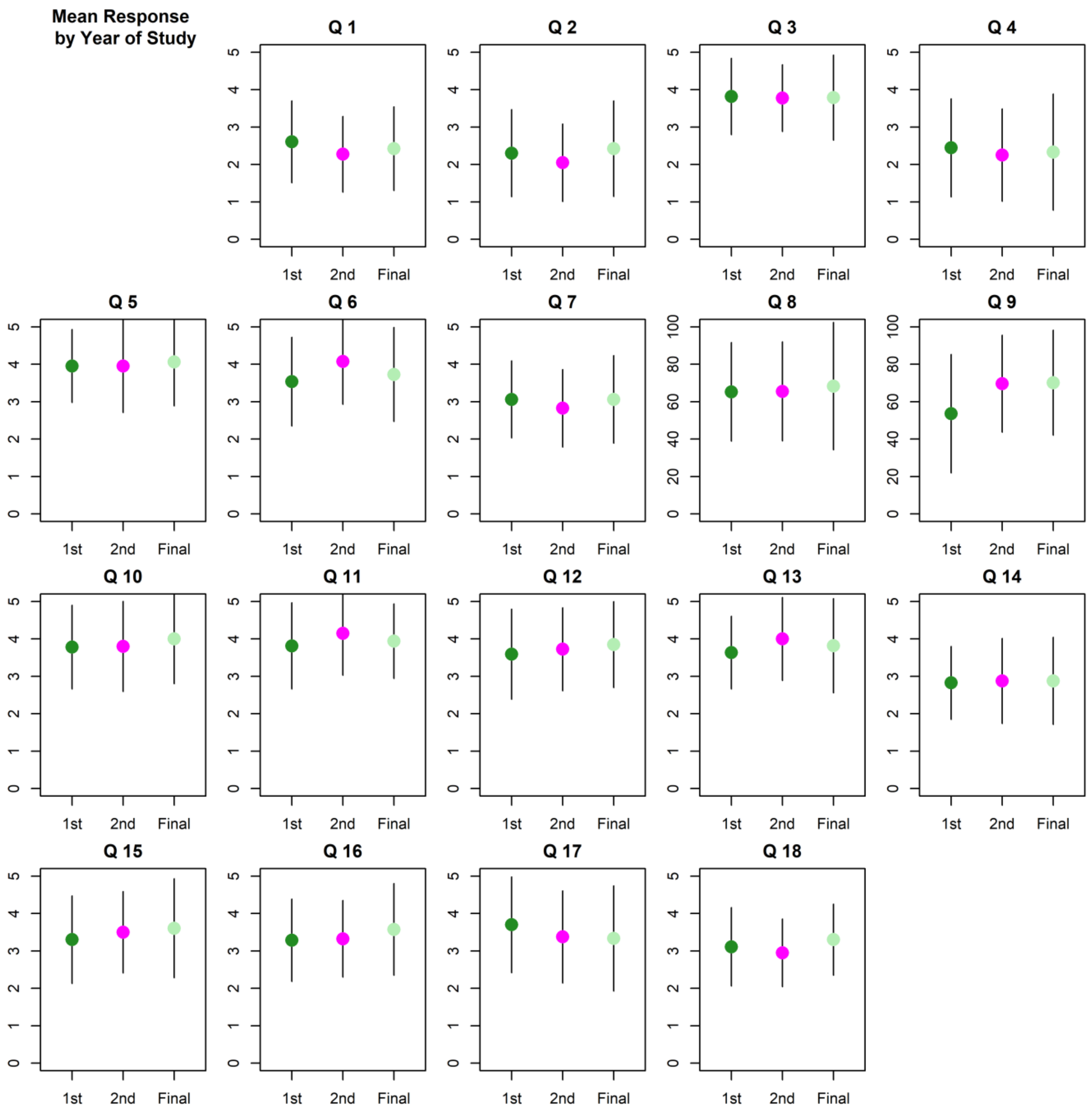

Figure S 3 Panel showing the mean response for each question by year of study (1st year, dark green circle; 2nd year, magenta circle; final year, light green circle). Bars depict s.d.

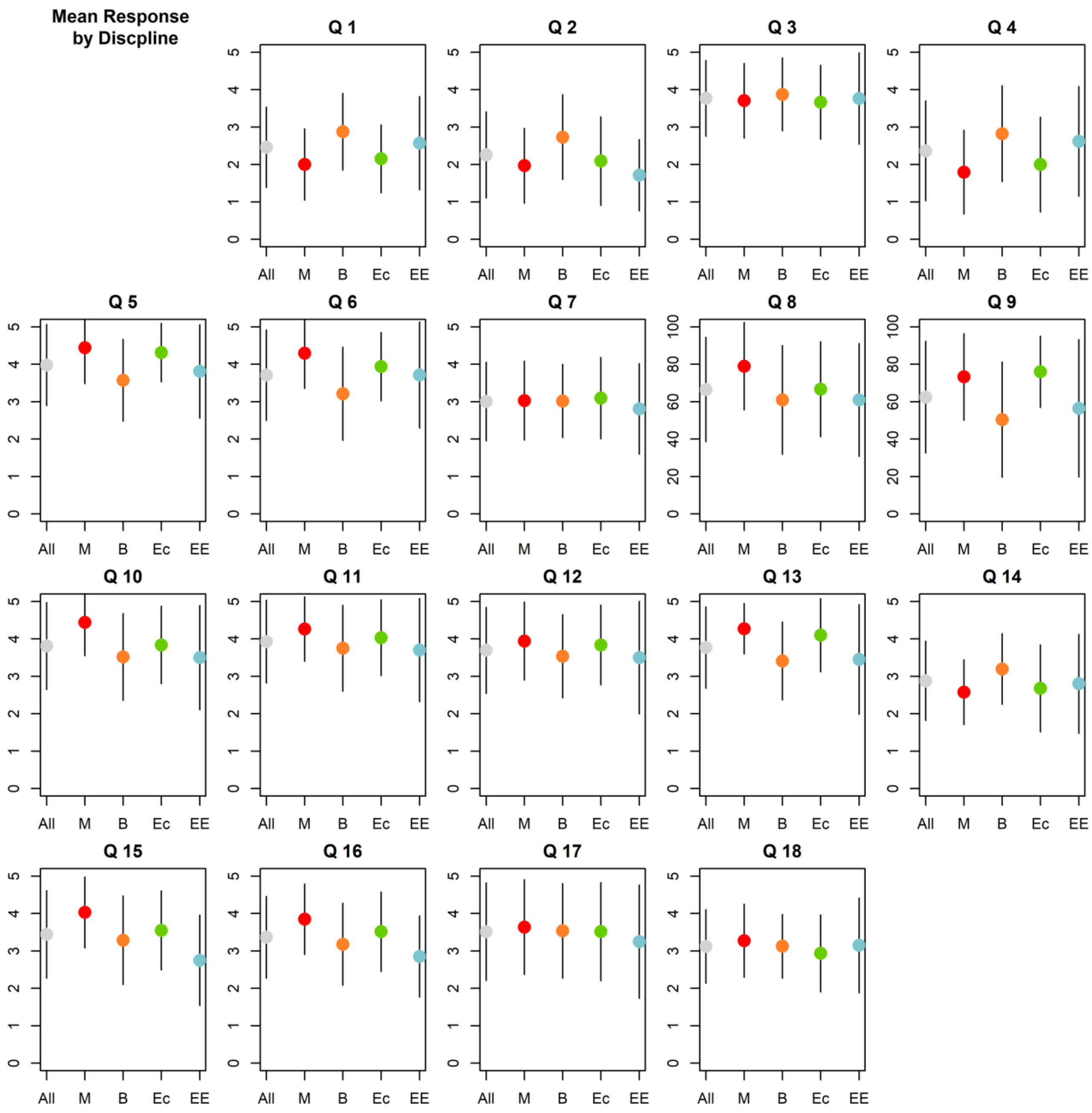

Figure S 4 Panel showing the mean response for each question by discipline (overall, grey circle; M - Maths, red circle; B - Business, orange circle; Ec - Economics, green circle; EE – Electronic Engineering, blue circle). Bars depict s.d.

8. References

Ahmed Y., Taha M. H., Al-Neel S., & Gaffar A. M. (2018). Students' perception of the learning environment and its relation to their study year and performance in Sudan. *Int J Med Educ*, 9, 145-150. doi:10.5116/ijme.5af0.1fee

Alamolhodaei, H. (1996). A study in higher education calculus and students' learning styles. PhD thesis, University of Glasgow. https://eleanor.lib.gla.ac.uk/record=b1594527

Ballantine, J. A. & Larres, P. M. (2004). A critical analysis of students' perceptions of the usefulness of the case study method in an advanced management accounting module: the impact of relevant work experience. *Accounting Education*, 13(2), 171-189. doi:10.1080/09639280410001676885

Bognar, L., Fáncsikné, É. H., Horvath, P., Joos, A., Nagy, B. & Strauber, G. (2018). Improved learning environment for calculus courses. *Journal of Applied Technical and Educational Sciences*, 8(4), 35-43. doi:10.24368/jates.v8i4.59

Boone, H. N., & Boone, D. A. (2012). Analyzing Likert Data. *The Journal of Extension*, 50(2), Article 48. doi:10.34068/joe.50.02.48

Byun, S. Y., Irvin, M. J., & Bell, B. A. (2015). Advanced math course taking: Effects on math achievement and college enrolment. *The Journal of Experimental Education*, 83(4), 439-468. doi:10.1080/00220973.2014.919570

Czocher, J. A., Tague, J., & Baker, G. (2013). Where does the calculus go? An investigation of how calculus ideas are used in later coursework. International *Journal of Mathematical Education in Science and Technology*, 44(5), 673-684. doi:10.1080/0020739X.2013.780215

Darmaji, D., Kurniawan, D. A., Astalini, A., Kurniawan, W., Anwar, K., & Lumbantoruan, A. (2019). Students' Perceptions of Electronic's Module in Physics Practicum. *Journal of Education and Learning*, 13(2), 288-294. https://eric.ed.gov/?id=EJ1325540

Devlin, M., & O'Shea, H. (2012). Effective university teaching: Views of Australian university students from low socio-economic status backgrounds. *Teaching in Higher Education*, 17(4), 385-397. doi:10.1080/13562517.2011.641006

Dündar, S. (2015). Mathematics teacher-candidates' performance in solving problems with different representation styles: The trigonometry example. EURASIA Journal of Mathematics, *Science and Technology Education*, 11(6), 1379-1397. doi:10.12973/eurasia.2015.1396a

Eng, T. H., Li, V. L., & Julaihi, N. H. (2010). The relationships between students' underachievement in mathematics courses and influencing factors. *Procedia-Social and Behavioral Sciences*, 8, 134-141. doi:10.1016/j.sbspro.2010.12.019

Entwistle, N., McCune, V., & Hounsell, J. (2002). Approaches to studying and perceptions of university teaching-learning environments: Concepts, measures and preliminary findings. Enhancing Teaching and Learning Environments in Undergraduate Courses Occasional Report, 1, 1-19. http://www.ed.ac.uk/etl/docs/ETLreport1.pdf

Ellis, J., Fosdick, B. K., & Rasmussen, C. (2016). Women 1.5 times more likely to leave STEM pipeline after calculus compared to men: Lack of mathematical confidence a potential culprit. *PloS one*, 11(7), e0157447. doi:10.1371/journal.pone.0157447

Fedesco, H. N., Kentner, A., & Natt, J. (2017). The effect of relevance strategies on student perceptions of introductory courses. *Communication Education*, 66(2), 196-209. doi:10.1080/03634523.2016.1268697

Ferreira, A., & Santoso, A. (2008). Do students' perceptions matter? A study of the effect of students' perceptions on academic performance. *Accounting & Finance*, 48(2), 209-231. doi:10.1111/j.1467-629X.2007.00239.x

Hagman, J. (2019). Towards a Forward-Thinking College Calculus Program. In Theorizing STEM Education in the 21st Century. *IntechOpen*. doi:10.5772/intechopen.77870

Hagman, J. E., Johnson, E., & Fosdick, B. K. (2017). Factors contributing to students and instructors experiencing a lack of time in college calculus. *International Journal of STEM Education*, 4(1), 1-15. doi:10.1186/s40594-017-0070-7

Harackiewicz, J. M., Smith, J. L., & Priniski, S. J. (2016). Interest matters: The importance of promoting interest in education. *Policy Insights from the Behavioral and Brain Sciences*, 3(2), 220-227. doi:10.1177/2372732216655542

Hensel, R. A., & Hamrick, T. R. (2012). Comparison of paths to calculus success. In American Society for Engineering Education. *American Society for Engineering Education*. doi: 10.18260/1-2--21092

Hitt, F., & González-Martín, A. S. (2016). Generalization, covariation, functions, and Calculus. In A. Gutiérrez, G. L. Leder & P. Boero (Eds.), Second Handbook of Research on the Psychology of Mathematics Education. The Journey Continues, 3-38. Rotterdam: Sense Publishers. doi:10.1007/978-94-6300-561-6_1

Johns, C. (2020). Self-Regulation in First-Semester Calculus. *International Journal of Research in Undergraduate Mathematics Education*, 6, 404-420. doi:10.1007/s40753-020-00114-9

Joshi, A., Kale, S., Chandel, S., & Park, D. K. (2015). Likert scale: explored and explained. *British Journal of Applied Science & Technology*, 7(4), 396-403. doi:10.9734/BJAST/2015/14975

Jungert, T., Levine, S., & Koestner, R. (2020). Examining how parent and teacher enthusiasm influences motivation and achievement in STEM. *The Journal of Educational Research*, 113(4), 275-282. doi:10.1080/00220671.2020.1806015

Kiarie, S. M. (2016). Effects of Teachers' Perceptions on Students' Perceptions and Achievement in Environmental Education in Secondary School Biology in Gilgil Sub-County Nakuru County, Kenya. International *Journal of Environmental and Science Education*, 11(12), 5736-5761. https://eric.ed.gov/?id=EJ1115678

Kay, R. and Kletskin, I., 2012. Evaluating the use of problem-based video podcasts to teach mathematics in higher education. *Computers & Education*, 59(2), 619-627. doi:10.1016/j.compedu.2012.03.007

Kinnear, G. (2018). Delivering an online course using STACK. In Proceedings of the STACK Conference.

Kokotovich, V. (2008, September). Cooperative, Cross-Discipline Teaching and Learning. In International Conference on Cooperative Design, Visualization and Engineering, 216-224. Springer, Berlin, Heidelberg. doi:10.1007/978-3-540-88011-0_30

Kunter, M., Tsai, Y.-M., Klusmann, U., Brunner, M., Krauss, S. & Baumert, J. (2008). Students' and mathematics teachers' perceptions of teacher enthusiasm and instruction. *Learning and Instruction*, 18(5), 468-482. doi:10.1016/j.learninstruc.2008.06.008

Lazarides, R., Buchholz, J., & Rubach, C. (2018). Teacher enthusiasm and self-efficacy, student-perceived mastery goal orientation, and student motivation in mathematics classrooms. *Teaching and Teacher Education*, 69, 1-10. doi:10.1016/j.tate.2017.08.017

Leu, K. (2017). Beginning College Students Who Change Their Majors within 3 Years of Enrollment. Data Point. NCES 2018-434. National Center for Education Statistics. https://eric.ed.gov/?id=ED578434

Li, Y., & Singh, C. (2021). Effect of gender, self-efficacy, and interest on perception of the learning environment and outcomes in calculus-based introductory physics courses. *Physical Review Physics Education Research*, 17(1), 010143. doi:10.1103/PhysRevPhysEducRes.17.010143

Madeira, V. R., de Souza, A. L. L., Peixoto, A., & da Gama Afonso, H. C. A. (2019). A Calculus Project to Support Students that Enter Engineering Courses. In 2019 IEEE Global Engineering Education Conference (EDUCON), 1224-1227. IEEE. doi:10.1109/EDUCON.2019.8725142

Marrongelle, K. A. (2001). Physics experiences and calculus: How students use physics to construct meaningful conceptualizations of calculus concepts in an interdisciplinary calculus /physics course. Unpublished doctoral dissertation, University of New Hampshire, Durham.

Minor, E. C. (2016). Racial differences in mathematics test scores for advanced mathematics students. *The High School Journal*, 193-210. https://www.jstor.org/stable/44075323

Newton, G., & McCunn, P. (2015). Student perception of topic difficulty: Lecture capture in higher education. *Australasian Journal of Educational Technology*, 31(3). doi:10.14742/ajet.1681

Osman, K., Hiong, L.C. & Vebrianto, R. (2013). 21st century biology: an interdisciplinary approach of biology, technology, engineering and mathematics education. *Procedia-Social and Behavioral Sciences*, 102, 188-194. doi:10.1016/j.sbspro.2013.10.732

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rasmussen, C., & Ellis, J., (2013). Who is switching out of calculus and why. In Proceedings of the 37th Conference of the International Group for the Psychology of Mathematics Education (Vol. 4, pp. 73-80). PME.

Rasmussen, C., Marrongelle, K., & Borba, M.C. (2014) Research on calculus: what do we know and where do we need to go? *ZDM Mathematics Education*, 46, 507–515. doi:10.1007/s11858-014-0615-x

Riegle-Crumb C & Grodsky E. (2010). Racial-Ethnic Differences at the Intersection of Math Course-taking and Achievement. *Sociology of Education*. 83(3), 248-270. doi:10.1177/0038040710375689

Sahin, A., Cavlazoglu, B., & Zeytuncu, Y.E., (2015). Flipping a college calculus course: A case study. *Journal of Educational Technology & Society*, 18(3), 142-152. https://www.jstor.org/stable/10.2307/jeductechsoci.18.3.142

Sevimli, E. (2016). Do calculus students demand technology integration into learning environment? case of instructional differences. *Int J Educ Technol High Educ*, 13, 37.doi:10.1186/s41239-016-0038-6

Sullivan, G. M., & Artino, A. R., (2013). Analyzing and interpreting data from Likert-type scales. Journal of Graduate Medical Education. 5(4), 541-2. doi:10.4300/JGME-5-4-18

Tall, D., Smith, D., & Piez, C. (2008). Technology and Calculus. In Heid, M. K., & Blume, G. W (Eds), Research on Technology and the Teaching and Learning of Mathematics, Volume I: Research Syntheses, 207-258.

Tang, H. E., Julaihi, N. H., & Voon, L. L. (2013). Attitudes and perceptions of university students towards calculus. *Social and Management Research Journal*, 10(1), 1-39. https://ir.uitm.edu.my/id/eprint/13111

Ting, D. H., & Lee, C. K. C. (2012). Understanding students' choice of electives and its implications. *Studies in Higher Education*, 37(3), 309-325. doi:10.1080/03075079.2010.512383

Tudor, J., Penlington, R., & McDowell, L. (2010). Perceptions and their influences on approaches to learning. *Engineering Education*, 5(2), 69-79 doi:10.11120/ened.2010.05020069

Vahey, P., Rafanan, K., Patton, C., Swan, K., van't Hooft, M., Kratcoski, A., & Stanford, T. (2012). A cross-disciplinary approach to teaching data literacy and proportionality. *Educational Studies in Mathematics*, 81(2), 179-205. doi:10.1007/s10649-012-9392-z

Weurlander, M., Cronhjort, M. and Filipsson, L. (2017). Engineering students' experiences of interactive teaching in calculus. *Higher Education Research & Development*, 36(4), 852-865. doi:10.1080/07294360.2016.1238880

Willmot, P. & Simms, R. (2018). Mathematics Education for 21st Century Engineering; extended abstract. Proceedings EERN spring Colloquium (pp. 69-70)

Yoo, D. M., & Kim, D. H. (2019) The relationship between students' perception of the educational environment and their subjective happiness. *BMC Med Educ*, 19, 409 (2019). doi:10.1186/s12909-019