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How prepared do students feel for the quantitative nature of a Biosciences degree?

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Quantitative abilities and techniques are vital in modern biosciences from lab calculations and classical hypothesis testing to the growth of ‘omics’ and big data. Long before the transition between Higher Education and the workplace can be considered, the transition between Secondary and Higher Education must be. Students doing bioscience degrees at a UK university were surveyed to ascertain the factors that prepared students best for the quantitative nature of a biosciences degree.
Student perceptions of biosciences as a quantitative subject altered once they began degree level study. Students who studied mathematics post-16 felt more prepared for the quantitative nature of their degree. Secondary level biology does not prepare students for the quantitative nature of degree level biosciences. Student’s felt that physics, computer studies, geography and psychology were subjects which contributed alongside mathematics, biology and chemistry to their secondary quantitative education.
Post-16 mathematics is only an entry requirement for 1of 49 biosciences courses across the UK’s Russell Group universities.

Most students do not feel prepared by their Secondary Education for the quantitative nature of a biosciences degree and Higher Education Institutions do not ask for quantitative qualifications. This study highlights the lack of preparedness perceived by students and the potential discord in this field between Secondary and Higher Education.

Keywords: Quantitative Biology; preparedness; Mathematics; Transition

Introduction

Biosciences have evolved into interdisciplinary fields. There is an increasing demand for the understanding of mathematical, physical science and computer programming skills to store, process and analyse increasing quantities and complexities of data (Kang *et al.*, 2015). Since 2000, several reports have been released calling for better integration of quantitative teaching into the undergraduate biosciences disciplines (Aikens & Dolan, 2014; Feser *et al.*, 2013; Labov *et al.*, 2010) These all echo the same concerns regarding the expanding and rather misleading lag between current biosciences research and teaching content.

Unlike with undergraduate education, there remains an ambiguity as to whether secondary education has managed to harmonise biology and mathematics, or whether students at the Secondary level are still under the outdated impression that biology is relatively maths-free.

According to a report by the British Academy (Mansell, 2015), UK school pupils generally only rank in the middle of developed nations in mathematics. The report recognises that not only subjects formally labelled as mathematics or science can contribute to the enrichment of quantitative skills. It includes in its vision statement that the UK government must work to better embed quantitative skills into non-mathematics subjects within the national school curricula; indicating that the majority of quantitative skills are still introduced through Science and Mathematics.

At approaching twenty years since the release of the BIO2010 (National Research Council, 2003), many suggestions of how to better integrate quantitative techniques into undergraduate teaching have been implemented by higher education institutions, yet a report by the Organisation for Economic Co-operation and Development showed that the UK's graduates were recorded amongst the worst in the developed world for their mathematics skills (OECD, 2015).

Both the report by the British Academy and the report, Vision for Science and Mathematics Education (The Royal Society, 2014) raise concern about the number of secondary students studying science and mathematics at post-16 level. Both clearly prioritise in their vision statements that science and mathematics should ideally be studied up to the age of 18. Compounding the shortage of students studying these subjects, a decline in numeracy skills among bioscience undergraduates in the 1990s was identified (Tariq, 2002).

Sections of the brain involved in decision making, planning and awareness continue to develop through adolescence, hence, compulsory learning of data-rich subjects like Science and Mathematics up to the age of 18 may embed quantitative understanding more deeply (Blakemore & Robbins, 2012).

The discussion as to whether students suffer with the transition from Secondary to Tertiary level quantitative understanding is not new. Referring to the state of universities in 1961, Thwaites publicised that students do not understand the mathematical ideas which university academics consider basic to their subject (Thwaites, 1972). A further study on the transition from post-16 study to university mathematics in 1985 suggested that very few students develop a critical understanding of mathematics when leaving secondary school (Bibby, 1985). In 1988 it was identified that a lot of work was required to advance post-16 quantitative biology (Shone, 1988). Biology and medical undergraduates who don't undertake mathematics at an advanced Secondary level struggle at university and don't appear to meet the quantitative expectations of university teaching staff (Jones, 2011; Zeegers, 1994). Others found that the difference was not in attainment when taught quantitative content, but self-belief

(Ben-Shlomo *et al.*, 2004). This implies that the quantitative preparation from non-mathematical subjects is somewhat lacking, and that either: a review of the quantitative content of the compulsory entry requirement subjects, usually biology, chemistry or both, is required; or, as would be within the control of Higher Education providers, a post-16 mathematics qualification as compulsory entry requirement for undergraduate biosciences study would be to the benefit transitioning students. Eighteen years ago, the assessment of first year bioscience undergraduates numeracy skills lead to the question, does Secondary Education adequately prepare individuals (Tariq, 2002)?

Secondary Education in the UK can be split into pre-16 and post-16. Pre-16 qualifications are commonly GCSEs (Scottish Nationals in Scotland), and common post-16 qualifications are A levels, BTEC level 3, International Baccalaureate (IB) and Access courses (Scottish Highers in Scotland).

There have been studies on student confidence in quantitative biology (Matthews *et al.*, 2015; Matthews *et al.*, 2013; Tariq & Durrani, 2012), and on student's perception of the value of and interest in quantitative biology (Andrews & Aikens, 2018; Matthews *et al.*, 2015). Furthermore, the mathematical ability of first year Bioscience undergraduates has been shown to be highly variable and low in average (Tariq, 2008).

Contextual, applied mathematical problems, such as those that may be faced in a biosciences degree were found to be more difficult than abstract questions (Tariq, 2008).

As a measure of progress, this study explores students' perceptions of quantitative biology, with the opinion of students on how well prepared they are for the quantitative nature of a biosciences degree, investigating the role of different academic subjects and qualifications, considering their pre-conceptions and their previous education.

Methods

A survey was disseminated to undergraduate biosciences students at the University of Warwick, a research intensive, Russell Group university in the UK, questioning the quantitative nature of their education. The survey was distributed via email to biosciences students and was shared on social media. The survey questions sought to investigate the following:

- Whether students believe that biosciences are a quantitative subject, and if their time at university has changed this view.
- Whether students believe they were introduced to the critical quantitative skills needed to begin their degree during their Secondary Education.
- Whether students believe they were introduced to the critical quantitative skills needed to begin their degree within their Secondary ***Biology*** education.
- Whether there is a difference in the perceptions of student's preparedness with different prior educations.

Full survey questions can be seen in Appendix 1. The nature of this survey means that responses were retrospective.

Due to the distribution of answers to some questions, pooling of categories was required. Answers for the highest Mathematics/Statistics qualification were pooled into 5 categories; GCSE Mathematics and GCSE Statistics, AS Mathematics and AS Statistics, A level Mathematics and A level Statistics, Access course and other.

The answers to the highest qualification in biology were pooled into 4 categories. GCSE and AS level were coupled to generate a 'lower than A level' category due to low numbers. Scottish National and Access course were added into the 'other' category.

All Likert scale responses were made binary, ‘strongly agree’ and ‘agree’ were coupled into an agree option, ‘neither agree nor disagree’, ‘disagree’ and ‘strongly disagree’ were coupled into a ‘do not agree’.

The binary categories ensured a sufficient number of responses in each category, and allowed the use of binary logistic regression with a cut value of 0.5, a widely used and understood analysis. For rigour, both backward and forward Wald methods were used to explore the potential for multiple optimum model fits. Within all logistic regression analyses, demographic variables age; gender, student status, year of study, place of study, type of secondary education institute attended, and highest Mathematics/Statistics, Chemistry and Biology qualifications achieved by the start of degree were used as independent variables. The lowest maths/statistics, chemistry and biology categories were set as reference categories. Further question responses were entered as independent variables. Pre-university perception of biosciences being quantitative was investigated as a predictor variable of, current perception of biosciences being quantitative, perception of preparedness, and opinion on Secondary biology preparing students for degree level quantitative biology. Association between perception of biosciences as a quantitative subject and that perception influencing degree subject choice was tested for by Chi-squared test.

The survey was administered in Qualtrics and the survey data collection took place between 20 May 2019 and 31 May 2019. Analysis was conducted in IBM SPSS 25.

The UK’s Russell Group of universities was used as a sample of entry requirements for degree level Biosciences.

Results

Degree Level Biosciences entry requirements

There are 49 biosciences courses across the 24 Russel Group universities; 20 are Biochemistry, 12 are Biomedical Science and 17 are Biology/Biosciences. Only one course requires A level or equivalent Mathematics. GSCE or equivalent Mathematics is listed as an entry requirement for only 30 of these courses, and only 11 specify a minimum grade B (grade 6). As such, 19 courses make no mention of Mathematics qualifications as entry requirements (https://www.ucas.com).

Demographic data

Demographic counts on the survey responders are given in Table 1. There were 210 survey responders, of which only 200 were complete. Of these, 60 (30%) identified as male, 137 (68.5%) female and 3 (1.5%) other. Of the responders, 192 (96%) were currently undergraduate students, while 195 (97.5%) attend or attended the University of Warwick. Most responders were in Secondary Education in the UK (180, 90%), the remaining 20 received their Secondary Education from 13 different countries. Only 198 responders gave their age, which ranged from 18 to 55 with a median of 20 (Fig. 1).

The highest Mathematics/Statistics qualifications were GSCE, 46 (23%), AS Level, 31 (15.5%), A level, 105 (52.5%), IB, 9 (4.5%), and other, 9 (4.5%). The highest Chemistry qualifications were GSCE, 27 (13.5%), AS level, 16 (8%), A level, 136 (68%), IB, 7 (3.5%) and other, 14 (7%). The highest Biology qualifications were GSCE or AS Level, 5 (2.5%), A level, 175 (87.5%), IB, 9 (4.5%), and other, 11 (5.5%).

Student belief in Biosciences as a quantitative subject

Response counts for the questions relating to student belief in biosciences as a quantitative subject, and their preparedness before stratification are given in table 2.

Before starting their degree, 77/200 (38.5%) biosciences students did not agree that biosciences were quantitative subjects. There were no significant demographic predictors of whether a student would agree or not. The number that did not agree that biosciences were quantitative subjects during and after their degree was 22/200 (11%). The influence of a student's pre-degree belief in biosciences as a quantitative subject on their choice to study biosciences was varied. There were individuals that were influenced to choose biosciences because they did believe it was a quantitative subject, but also those that were influenced to do so because they believed that it was not, Chi-squared analysis revealed no association between these variables. Although 22/200 (11%) of responders did not agree that biosciences were quantitative subjects, only 5.5% (11/199) of responders did not agree that Biological Scientists need quantitative skills in their career.

Perceptions of preparedness for the quantitative nature of a Biosciences degree

The survey asked biosciences students how prepared they felt for the quantitative elements in year 1 of their degrees (table 3), to which there were 199 responses. There were no significant demographic predictors. Students that agreed with the statement that biosciences are a quantitive subject were twice as likely to feel prepared for the quantitative nature of year 1 of their biosciences degree (table 4). Having a post-16 Mathematics and/or Statistics qualification made students more likely to feel prepared. Having an AS level made students 3.3 times more likely to feel prepared (OR: 3.347, $p = .015$), an A level 2.9 times more likely to feel prepared (OR:2.946, $p = .016$), an IB 7.3 times more (OR: 7.327, $p = .023$) and another Mathematics or Statistics qualification, 9.5 times more likely to feel prepared (OR: 9.561, $p = .010$). The group of other qualifications were mostly qualifications from abroad, and all represented a post-16 qualification.

The survey asked if Secondary Biology education prepared students for the quantitative nature of the first year of a biosciences degree, to which there were 199 responses. Due to collinearity between age and year of study, age was omitted from the analysis as year of study was more relevant and informative given that, despite the collinearity, age commonly fell into more than one year of study.

Most responders had A level Biology as their highest Biology qualification before their degree 175/200 (87.5%). Only 5 had a lower level qualification as their highest biology qualification. Whether students felt that their Secondary Biology education prepared them for the quantitative nature of the first year of a biosciences degree was bimodal (Figure 2). Only 71 (35.5%) agreed and 13 strongly agreed (6.5%). A logistic regression model was fitted to the binomial stratified agreement to Secondary Biology preparing students for the quantitative nature of year 1 of a biosciences degree. Year of study (OR: 1.470, $p = .008$), view on biosciences as quantitative before starting their degree (OR: 2.565, $p = .004$) and having an A level Mathematics qualification or Mathematics International Baccalaureate were significant predictors (table 5). The authors consider the significance of the highest mathematics qualification disingenuous to the question asked and as such the values are not presented here, but explained in the discussion.

Responders were asked if any subjects that they had studied other than biology, chemistry or mathematics/statistics, had helped prepare them for the quantitative nature of year 1 of a biosciences degree. 43/200 (23%) responders identified 45 instances of a subject studied that prepared them. These were physics (20), psychology (10), computing (8), geography (6) and economics (1).

Discussion

The proportion of biosciences students studying mathematics and/or statistics (77%) post-16 is encouraging, this represents an increase since (Tariq & Durrani, 2012) found that only 30% of Science and Technology undergraduate responders studied mathematics post-16. It suggests students with an interest in both subjects, or that students studied mathematics for the purpose of building skills to study biosciences.

There is a clear shift in whether students perceive biosciences to be quantitative from before they start their degree, to once they are on it or have finished it. This was apparent even taking account for possible revisionism that may come into play, given that students were asked both questions, at the same time, once their degrees had started, echoing a previous result that suggested that students judge the value of using Mathematics in Biology above their interest in it (Andrews & Aikens, 2018). Though the number of students that believed biosciences to be quantitative increased, the high proportion that did so before their degree is a sign that many students are suitably informed about their chosen subject. There were individuals that still did not consider biosciences to be quantitative once their degree had started. As a survey question, it is possibly a consequence of the question wording, which may lead the responder to assume it means that all fields of biosciences are quantitative, to which they rightly disagree. However, it is also possible that responders do not consider/understand that they are the Biological Scientists. They may disassociate themselves with the career of a Biological Scientist because they intend on doing something else but believe they can do enough to get their degree. It is possibly an issue of obstinance given the often reported but under analysed relative lack of regard and interest with and in mathematics by biosciences students (Wachsmuth *et al.*, 2017). Further study should seek to determine how and why biosciences students do not consider it to be a quantitative science. The high proportion of students 188/199 (94.4%) that believe that Biological Scientists need quantitative skills in their career is much higher than a study of Australian Sciences undergraduate students reported their perception of whether they would use quantitative skills in future (Matthews *et al.*, 2015), interestingly including all sciences, as the other Sciences are traditionally more quantitative.

The results are clear that mathematics training and thus qualifications post-16 are beneficial to students' feeling of preparedness when going on to study biosciences at university. The much larger sample of responders that have full A level (105) leads to a narrower confidence interval than that of AS level (31), and one that sits within the confidence interval of AS level. As such the slightly higher odds ratio for AS level Mathematics and/or Statistics over A level can be dismissed as an artefact of sample size. Holders of either were 3 times more likely to feel prepared for the quantitative nature of a biosciences degree. Holders of an IB are 7.3 times more likely to feel prepared. It is possible that the much higher odds ratio is an artefact of the small sample, however there is some evidence in market research that the IB more greatly encourages independent enquiry and nurtures an open mind over A levels (ACS & Schools, 2017), both traits that may lend themselves to greater acceptance of biosciences being quantitative, and thus lead to greater engagement. Being more likely to feel prepared with a higher mathematical qualification could be linked to Maths Anxiety, which is positively correlated at the Secondary education level with performance (Hill *et al.*, 2016).

Agreement with Secondary Biology preparing students for the quantitative nature of year 1 of a biosciences degree was split (Figure 2). A large proportion, 115/199 (58%) did not feel they were prepared by Secondary Biology as might be hoped. This result was predicted in part with post-16 mathematics qualifications, and as such those that did agree with the statement also had higher mathematics qualifications. This means that responders either were able to get more from their biology qualification *because* of their mathematics qualification or that they were unable to separate out the skills they had learned in the two subjects and therefore mis-attributed. As such, the proportion of responders agreeing with Secondary biology preparing them for the quantitative nature of year 1 of a biosciences degree may be over-inflated. That being the case or not, there are many students that believe that their Secondary biology education did not prepare them for a university biosciences degree.

Some responders identified other subjects that helped prepare them for the quantitative nature of their biosciences degree. That 26% of responders did so is of significant interest alone. It is not known what proportion of responders actually studied subjects other than biology, chemistry and mathematics post-16. It cannot be assumed that all students that studied physics, psychology, computing, geography or economics found them beneficial in the discussed way, but the number is surely limited more by the number of responders that studied these subjects post-16 as opposed to these subjects not contributing to quantitative familiarity and proficiency. Physics is a highly quantitative subject that lends itself to developing algebraic skills and Computing towards logical thinking, problem solving and data presentation. Computing is becoming more necessary for bioscientists (Barone *et al.*, 2017; Pevzner & Shamir, 2009) and the number of A level computing entrants is increasing (Joint Council for Qualifications, 2018) as is the number of schools offering computing at GCSE (Kemp *et al.*, 2016). Psychology and geography have statistical components that require some data handling, manipulation and testing, as evidenced in respective A level syllabuses from the leading UK Exam board (AQA, 2019a; AQA, 2019b). Only one responder identified an economics qualification, thus not much can concluded from it, however it is clearly a numerical subject, and that studying it should lead to an increased numerical ability or confidence is a reasonable assumption.

There is no reason to assume that studying any subject would have a negative effect on a student's perception of how well prepared they were for quantitative elements of biosciences.

Other demographic data was collected from responders. Age, gender, year of study, whether current or former student, Warwick or elsewhere, UK or other university location and type of secondary school (State, Grammar, Private/fee-paying, Home School) were collected, and none of these were found to be significant predictors of responder's judgements of their Quantitative Biology education, whereas a previous study of Australian students found that male biosciences students were significantly more confident in their Quantitative Skills (Matthews *et al.*, 2013), and another that males at American universities had greater interest than females, but there was difference in their perception of the value and use (Andrews & Aikens, 2018).

The survey results investigated here primarily targeted biosciences students at the University of Warwick. However, 5 (2.5%) responders had completed their undergraduate degree, of which 4 had been completed elsewhere. One responder was a current undergraduate student at another university. Neither having completed an undergraduate degree, nor that degree being elsewhere, whether previously or currently, was identified as a significant variable in the analyses.

The authors believe that the data being collected from primarily Warwick students does not limit the inference of the results. Much of the questioning relates to responder's interpretations of matters pre-university, as such the effect of their university destination will be limited to revisionism. Some questions relate to the experience of university level biosciences. In these cases, there is the possibility that the University of

Warwick’s curricula differs significantly from other Higher Education institutes (HEI). However, Royal Society of Biology Accreditation and courses mapped against the Quality Assurance Agency for Higher Education (QAA), combined with the non-significance of the HEI variable in the data suggests that results here are not specific to a single institution. Further to that, findings are similar to those of a previous study (Tariq, 2008). While these factors lead the authors to believe that inference can be made across similar institutions, there is scope to further this knowledge with the same process in multiple institutions.

The relatively short period of time for which the survey was open acted to limit the sample size. While unideal, the response rate had slowed to the point of suggesting that the maximum sample was close to being reached. Given the number of predictor variables in the final models, the sample size was enough to avoid positive and negative bias (Peduzzi *et al.*, 1996). A larger sample would have greater power and possibly elucidate further results. As such the results presented here could be considered a minimum that might be true of such a survey.

Asking the questions of students retrospectively may have led to some revisionism of their impression of the biosciences as a quantitative subject. Once they had experienced it at undergraduate level, they may have believed that they always considered it quantitative. However, the result here is that there is an increase in the number of students that think it is a quantitative subject after starting their degree, and so the result that could be lost to revisionism, is not. The retrospective nature has a more ambiguous effect on the perception of preparedness. Student ideas of how prepared they were when transitioning to degree level may have changed once the transition was made. While this retrospective study cannot explore that, surveying students once they know the realities of undergraduate biosciences is valuable. Although any change in perception does not necessarily equate to a difference in actual preparedness.

Here, we have shown there to be a discord between student interpretation and adequacy of quantitative training at Secondary Education and the quantitative skills required for a biosciences degree. The possession of a post-16 mathematics and/or statistics qualification clearly provides transitioning students either with skills that are beneficial to studying a biosciences degree or with confidence to tackle and engage with the quantitative elements of a biosciences degree. This result supports the previous literature documenting the struggles of biosciences students with quantitative skills and techniques (Jones, 2011; Tariq, 2008; Zeegers, 1994) made all the more pressing by the quantitative advances in the biosciences (Kang *et al.*, 2015; Mogilner, 2016).

However, HEIs are not requesting post-16 mathematics and/or statistics as an entry requirement for biosciences courses and transitioning students do not feel suitably prepared by their biology qualifications.

The results presented here indicate that students may not feel prepared for the quantitative elements of a biosciences degree given their prior conceptions of biology as a quantitative subject and their entry qualifications. As such we are not able to say if students are genuinely prepared, and further investigation of entry qualifications and bioscience degree performance is required. The perceived lack of preparedness may play a vital role in performance given confidence with the material (Nicholson *et al.*, 2013; Putwain *et al.*, 2013).

Where courses specify lower entry grade criteria if there is an additional Science qualification, there is evidence to suggest that computing, psychology and geography have quantitative content that are advantageous to a student transitioning into degree level biosciences, and as such could be considered that additional Science. Further to that, psychology and geography have content, other than that which is quantitative, that is relevant to biosciences degrees.

Educational Implications

As students do not feel suitably prepared, it highlights that HEIs may need to increase the dedicated quantitative training in their curricula as a remedial measure, as well as the oft reported quantitative skills integrated into other content, in order to prepare the bioscience workforce of the future. However, studying a subject at Secondary level should prepare students to transition to that subject at degree level. There is evidence to suggest that that is not the case with Secondary biology. Secondary Biology needs to reflect the modern biosciences, which require quantitative understanding. This should be present both in the form of familiarisation, and also as training. There are questions as to whether the current Secondary syllabuses have truly relevant quantitative content and if it is suitably integrated into the rest of the subject's content. If so, there is a question as to whether it is overly trivialised or potentially avoidable. The quantitative elements of Secondary Biology education require scrutiny.

The authors declare no conflict of interest.

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