Nonplussed students

Investigating student numeracy and educational background in a second year science course without a mathematical prerequisite and improving student numeracy through the use of detailed worked examples.

Original title: Improving numeracy in second year physiology students through the use of detailed worked examples.

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Snapshot of the case

The numeracy background of Physiology 233 (PHSL233) students was explored and the number of these students not meeting a minimum numeracy benchmark (≈ year 9 high-school) was measured, to determine the effects of numeracy on academic performance in a second year science course without a mathematics pre-requisite. Student numeracy was low and 15% of students did not meet the year 9 benchmark. Furthermore, poor numeracy correlated with increased course failure rate. 62 % of students had not completed maths papers at university and 4% have only obtained NCEA level 2. Despite this, 71% of students rated themselves as “confident” or “extremely confident” with the maths required for PHSL233. High confidence in mathematical ability correlated with course failure. Numeracy resources for the PHSL233 laboratory course were developed and presented to students as modules on the XOtago platform (https://x.otago.ac.nz). XOtago resources are being revised for 2015 based project numeracy findings.

Introduction

Poor numeracy at first year university level has been linked to poor achievement in general biology and biomedical science courses (McNaught and Hoyne, 2013; Rylands and Coady, 2009; Tarq, 2002; Wilson, 2013). However, there are few studies addressing the effects of poor numeracy on biological science students pursuing more specialised second and third year courses. Physiology is an example of a quantitative biological science in which students require a higher level of mathematical proficiency to attain graduate attributes in critical thinking and scholarship. Students at the University of Otago specialise in physiology in the second year of their degree. PHSL233, one of three second year physiology papers taught at Otago, includes an introduction to the discipline of electrophysiology (the study of the driving forces that enable the movement of ions and water in biological tissues) which has a strong basis in mathematics and physics.

The PHSL233 paper does not have any mathematical prerequisites; rather students are required to have passed two general human anatomy and physiology papers (HUBS 191 and HUBS

192) and two first year papers selected from biochemistry (BIOC 192), cellular biology (CELS 191), chemistry (CHEM 191), and physics (PHSI 191). Thus, while all of our students have achieved university entrance, we cannot presume anything about their mathematical backgrounds, and needless to say it is likely to be diverse. Anecdotal observations by the staff teaching the laboratory component of the PHSL233 course, and the related 300 level paper PHSL 343, indicate that some students do lack numeracy skills e.g., cannot interconvert between millilitre (ml) and microliter (µl), cannot use ratios when calculating dilutions, cannot manipulate simple fractions and cannot rearrange simple 3-term equations. Furthermore, in 2012 and 2013 more than half of the students rated the PHSL233 course as "much too hard" in course evaluations. These observations indicate that a number of students undertaking the PHSL233 courses have either inadequate procedural numeracy, an inability to contextualise their mathematical knowledge to solve physiology specific problems, or both.

In 2014 the minimum mathematics requirement for university entry (UE) was reduced to 10 credits at level 1 from 14 credits at level 1 (NZQA website www.nzqa.govt.nz), there is a concern that numeracy amongst students attending university will fall (Linsell and Casey, 2013). Paradoxically, the Tertiary Education Strategy 2014 -2019 that was jointly published by the New Zealand Ministry of Business, Innovation and Employment and the Ministry of Education (Ministry of Education, 2014) proposes directions that could increase the numbers of students studying science subjects at a tertiary level. For example: Increasing the number of young people attaining level 4 qualifications (i.e. undergraduate degree level) and addressing skills shortages in subjects required for innovation and economic growth in science, technology, engineering and mathematics (STEM) industries. Collectively, these factors indicate science educators in tertiary institutions could be faced with more students and that these students will have increasingly diverse mathematical backgrounds. As PHSL233 lacks a mathematical prerequisite, students taking this course make an interesting case study when determining how to deal with the influx of students with reduced numeracy predicted by recent changes to NCEA and government education policy. There are two possible approaches to the problem of students with poor numeracy background undertaking the PHSL233 course: introducing more stringent mathematical prerequisites to exclude these students or, alternatively, helping them by changing our approach to teaching mathematical concepts and by providing additional numeracy resources. This second approach will require us to understand the numeracy of our learners in more detail and to understand some of the ways students learn mathematical concepts.

What is numeracy?

Numeracy is a term that describes the balance between mastery of abstract mathematical rules and procedures and the contextual application of those rules and procedures in everyday life or to a specific discipline or learning environment (Coben, 2003; Sweller, 1994). For example, addition and subtraction are procedural mathematical skills. Calculating the total cost of various goods and the change required after payment are addition and subtraction skills contextualised to shopping. The distinction between mathematics and numeracy matters because it is possible to understand mathematical concepts either in theory or in one specific context and be unable to apply

them in another (Carraher, Carraher, and Schliemann, 1985, Evans, 2000). Educators need to take account of the way in which students apply knowledge and transfer knowledge to new contexts.

Initial numerical learning involves sequential understanding of different ways of representing numbers and the relationships between numbers. Mathematical learning progressions are an attempt to describe the theoretical learning trajectory students undertake as they achieve competency in increasingly sophisticated number strategies that form part of a learning thread (Tertiary Education Commission, 2008; Simon, 1995). For example, if one considers place value to be a learning thread, the initial understanding involves counting up to a certain number, for example 10. This allows a learner to divide larger numbers into groups of that amount and determine a total number of objects by counting the groups (e.g. understanding that 5 groups of 10 is 50 objects). At the higher end of this learning progression is the awareness that a single object may be divided into 10, 100, 1000 or more parts that can be represented as decimals, fractions, percentages or exponents (Tertiary Education Commission, 2008). Number strategies are the mental building blocks used when solving both abstract and contextualised mathematical problems, the degree of mastery of number strategies is related to the type of strategy a learner can, potentially, use when solving problems (Byrnes, 1992; Tertiary Education Commission, 2008). However, many investigations also point out that the interrelationship between acquisition of number knowledge and learning to performing mathematical procedures makes it hard to measure them independently and thus determine the sequence in which each occurs (Schneider and Stern, 2010).

Learning to use number knowledge to solve mathematical problems or perform abstract mathematical procedures occurs in well-defined stages. Initially a learner will undertake schematic acquisition of a skill, which means learning by mechanical application of several number strategies or emulating a set of rules (Cooper and Sweller, 1987; Sweller, 1994). With practice, a learner will acquire ability to remember rules or steps so that they can apply them to new problems without reference. Finally, when a learner no longer needs to refer to rules and steps to solve a problem, the pathway becomes automatic (Sweller, 1994). Transfer, the ability to take an abstract problem solving skill and contextualise it to a “real” situation can be taught in similar steps to abstract learning, i.e. learners emulate and become practiced at applying a procedure or method in a specific context (Cooper and Sweller, 1987). Alternatively, some learners may achieve such a high degree of understanding of a mathematical procedure that they recognise when it can be applied regardless of the context.

Worked examples as a teaching strategy for numeracy

The calculations students are required to perform in PHSL233 are not simply abstract mathematical calculations but problems specific to the context of physiology. When teaching applied mathematical concepts to diverse learners, such as the PHSL233 students, there will be many different ways in which they may not understand. To broadly categorise these; firstly, there may be learners who are limited in the strategies they can apply to a numerical problem or procedure because they have not progressed far enough along the learning trajectory in a given learning thread. Secondly, there may be students who have adequate number knowledge but they cannot connect strategies together to solve problems in an automatic way, i.e. they have inadequate

procedural knowledge relating to mathematical problem solving. Finally, there may be students who have adequate procedural problem solving ability but cannot contextualise their skills to physiology.

One teaching strategy that has been shown to help with both learning to solve abstract procedures and the contextual transfer of those skills to science subjects is the worked example (Kirschner, 2006; Thompson, et al. 2013; Van Gog, Paas, Van Merrienboer, 2004). At their most basic, worked examples are example maths problems that have been solved to show all of the steps a person should take to get the correct answer, they provide an analogy which learners can emulate when solving practice problem (Ward and Sweller, 1990; Van Gog, Paas, Van Merrienboer, 2004). However, the way in which worked examples are constructed plays a role in their effectiveness as a tool for teaching applied problem solving, many of the suggested strategies have a strong grounding in cognitive load theory (Ward and Sweller, 1990). Split attention studies demonstrate that worked examples are more successful if they integrate written explanations and worked calculations, as opposed to having the calculations and explanations separate (Chandler and Sweller, 1992). The theoretical reason for this is that when different modes of explanation are separate, the student will "split" their attention as they attempt to integrate the two modes. Conversely, if modalities are combined the students attention is not split and the worked example is less taxing to follow. Providing "sub goals" or dividing sections of complex worked examples together into "steps" may be more successful than providing a long, continuous worked example (Ward and Sweller, 1990).

The objectives of this project were:

Firstly, to understand the mathematical education background of our physiology student cohort. To achieve this, a survey was administered to students asking participants (n=122) to describe the highest mathematical qualification they have passed and their own perceptions of their ability to perform the mathematical calculations required for their course. We also measured the numeracy of this group of students (n= 120) using the Tertiary Education Commission (TEC) Numeracy for Adults Assessment Tool, tool that has been widely used in the New Zealand tertiary education sector, in particular the vocational training sector (Linsell and Anakin 2012; Linsell and Casey 2013).

Our second objective was to design numeracy resources, to assist students to participate in our laboratory classes, and later, to improve upon these resources based on student numeracy scores and survey results. For each of the six laboratory classes students were provided with worked examples for the calculations they are required to perform during the lab and a series of 6 self-test questions pertaining to the laboratory content, at least two of which were specific to mathematical calculations. When we developed these resources, the guidelines outlined in the introduction, in particular those described in Ward and Sweller (Ward and Sweller, 1990) were used. In particular, we integrated calculations, written descriptions, and visual elements such as diagrams. These resources were presented on XOtago (https://x.otago.ac.nz), an on line platform which is an adaption of the edX platform that is used internationally to host on line courses (https://www.edx.org/about-us). Students were given unlimited access to these resources before during and after laboratory classes.

Methods

Numeracy Assessments

Student numeracy was measured using the Tertiary Education Commission (TEC) numeracy tool for adults (http://www.tec.govt.nz/Resource-Centre/Software-tools/Literacy-and-Numeracy-for-Adults-Assessment-Tool/). This test is an on-line adaptive assessment tool that has been widely used in the New Zealand tertiary education sector, in particular the vocational training sector (Linsell and Anakin, 2012; Linsell and Casey, 2013; Tertiary Education Commission 2008). This test is adaptive in that not all students answer the same set of questions, rather the level of question each student is presented with changes based on correct or incorrect answers given in previous questions.

TEC numeracy assessment provides students with a numeracy score (from 100 to 1000) that is calculated on the basis of the number of questions answered correctly and the difficulty of each question (Tertiary Education Commission, 2008; Figure 1). Students who score below 700 in this numeracy test have a numeracy level below the year-9 benchmark (Linsell and Anakin 2012; Linsell and Casey 2013). Furthermore, when teaching second year science students we tend to presume that our students have a level of numeracy well above the year 9 benchmark, we felt it important to identify or put a number on these presumptions. Based on the types of questions asked in the numeracy assessment we decided that a numeracy score of above 800 would indicate a level of numeracy that met our assumptions.

The numeracy assessment uses questions that test student ability in six key learning threads: number sequence, place value, proportional reasoning, addition and subtraction, multiplication and division and measurement. Each question is given a level from 1 - 6 according to where it falls on a standardised adult numeracy learning progressions for each thread (Tertiary Education Commission, 2008; Figure 1) with the boundary between level 5 and level 6 representing the cut off for the year 9 benchmark. This enables educators to identify specific numeracy skills a student needs to learn in order to progress.

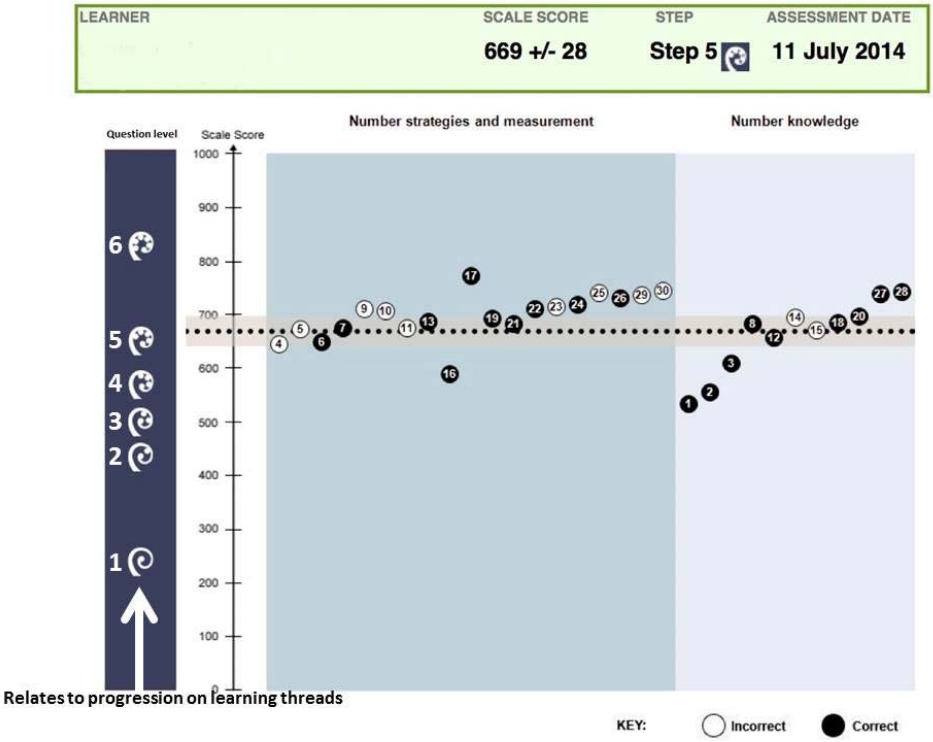

Figure 1. TEC Numeracy Assessment Tool numeracy analysis.

The TEC numeracy assessment provides students with a numeracy score, from 100 to 1000, which is calculated on the basis of the number of questions answered correctly (black dots) or incorrectly (white dots) and the difficulty of each question. Each question is also given a level, from 1-6, in relation to adult numeracy learning progressions for six different learning threads. These are published by the tertiary education commission (Tertiary Education Commission, 2008).

Investigating the educational background of our students

During an introductory laboratory, students were invited to complete a survey that asked the following questions:

1) How did you gain university entrance?

2) What is the highest mathematics qualification or paper you have passed?

3) In what year did you last study mathematics? At what level was this study?

4) How do you feel about your ability to do the mathematics required to complete your degree?

We obtained responses, or partial responses, from 122 students. Survey data were compiled by categorising students responses, 1) will find it hard, 2) Ok but not great, 3) confident, and 4) very confident, and then correlating the responses with numeracy measurements and course failure. Student survey responses were also used to identify issues and experiences with mathematics that were not identifiable in the numeracy assessment.

Measurements of student achievement in PHSL233

In PHSL233, the student's final grade is composed of 30% of their terms mark (which is in itself 50% from each of two terms tests) and 70% from their final exam mark. Students need to achieve an average mark of 40% in their two terms tests and attend a minimum number of laboratory class in order to sit the final exam. This presents some problems for analysis as students who do not meet terms requirements cannot sit the final exam and thus do not have a final grade that is comparable to those that do. In this report we will discuss student achievement in terms of course failure rate (defined as the % of students who did not pass the course either because they failed terms or because they failed the final exam. Within the terms test questions there are calculation based multiple choice questions that relate to laboratory material that students have previously found problematic. As a indicator of the success of our numeracy resource, I have compared the achievement of this year's students in these "problematic questions" with the achievement of last year's students (who did not have access to numeracy resources).

Numeracy resource development

For each of the six laboratory classes students were provided with worked examples for the calculations they are required to perform and 6 self-test questions pertaining to the laboratory content, at least two of which were specific to mathematical calculations These resources were presented on XOtago (https://x.otago.ac.nz), an online learning platform which is an adaption of the edX platform (https://www.edx.org/about-us).

When initially developed, the detailed worked examples followed the guidelines outlined in the introduction to this report (Ward and Sweller, 1990) in that they integrated calculations, written

descriptions and where applicable visual elements such as diagrams. Revisions of these resources for the second semester of 2015 will include elements of numeracy identified as problematic in the numeracy test and survey.

The on line platform was chosen to encourage students to use the worked examples and related self-test questions in diverse ways. Firstly, by making these resources available on line, students could use the worked examples to prepare prior to laboratory classes. Secondly, because students have access to computers and the internet during laboratory classes they could use worked examples as a guide when completing lab work. Thirdly, it was anticipated that students would use the self-test questions and worked examples directly after lab classes to consolidate their learning or during the exam preparation period as a revision resource.

Key findings

Numeracy

Numeracy scores

In 120 students (from a total cohort of 170 PHSL233 students) completed the TEC numeracy assessment; of these students 18 (15%) did not meet the minimum numeracy benchmark, described as being below the level of a year 9 student (Linsell and Anakin 2012) (Figure 2a). The majority of the students who completed the test, 62 students (55%) achieved a numeracy score between 700 and 799 which is above the year 9 benchmark but below 800, the level we set as matching our presumptions about the numeracy of our second year science students. The overall course failure rate for PHSL233 was 14%, which was similar to previous years (2013, 2012, 2011). However, students scoring below 800 in the numeracy assessment had a higher failure rate of 19% (Figure 2b).

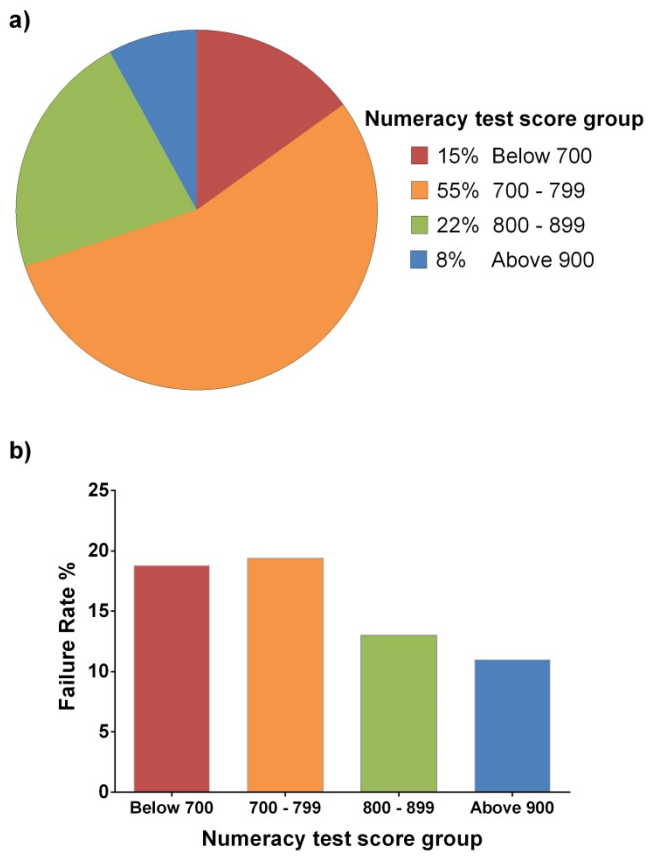

Figure 2. TEC Numeracy assessment tool numeracy scores for the PHSL233 student cohort.

a) Shows the proportion of students in the PHSL233 cohort who obtained a numeracy score of less than 700 (red), 700-800 (orange), 800-899 (green), and above 900 (blue). b) Shows the relationship between student numeracy score and course failure rate.

Numeracy learning threads

Numeracy assessment results for 120 students were analysed to determine the number of students answering questions incorrectly for each of the 6 learning threads (number sequence, place value, proportional reasoning, addition and subtraction, multiplication and division, and measurement) (Figure 3a-f). The boundary between level 5 and level 6 on the learning progressions represents the cut off point for the year 9 numeracy benchmark for each learning thread. Results show that while there were some students answering questions incorrectly at level 5 or below for each learning thread, the results for place value and measurement were of most concern. For the place value learning thread, 28 students (23% of students) answered questions placed at level 5 incorrectly and 10 students (8% of students) answered questions that were placed below level 5, (i.e. levels 4, 3, 2 and 1 combine) incorrectly. For the measurement learning thread 46 students (36% of students) answered questions placed at level 5 on the learning progressions incorrectly and 8 students (7% of students) answered questions placed below level 5 on the learning incorrectly.

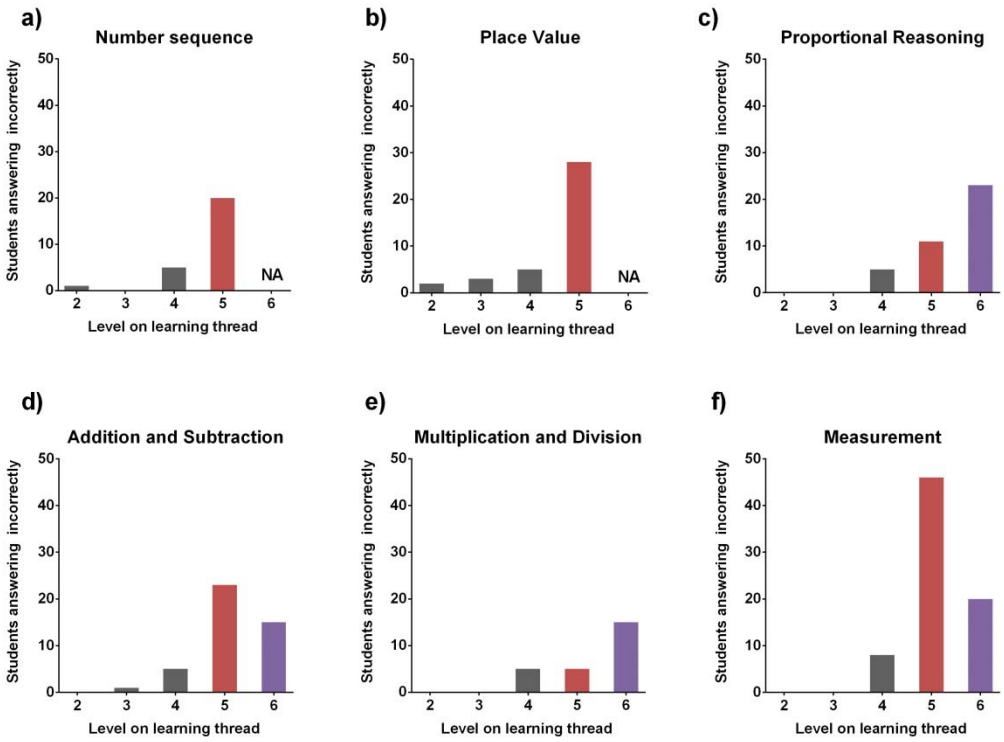

Figure 3. TEC Numeracy assessment tool numeracy scores for the PHSL233 student cohort.

The number of students (n=120) answering questions incorrectly at below level 5 (grey), at level 5, (red bars) and above level 5 (purple bars) in standardised learning progressions for the 6 learning threads: a) number sequence, b) place value, c) proportional reasoning, d) addition and subtraction, e) multiplication and division, f) measurement. The number sequence and place value threads do not have level 6 questions as at this stage these learning threads merge with the other learning threads. The boundary between level 5 and level 6 represents the cut off point for the year 9 numeracy benchmark.

Educational background

Of the 122 students who provided detailed information regarding their mathematical education, the majority, 61.7%, have not completed any mathematics papers at university level (Figure 4a) and 4.2% have only obtained NCEA level 2 (year 12) or equivalent (Figure 4a). Nevertheless, 23.3% have completed a 100 level university statistics paper and 12.5% a 100 level university mathematics paper and 2.5% have studied mathematics or statistics at 200 level or above (Figure 4a). Of those who had completed a first year university mathematics paper (15 students), 8 specified that they had studied MATH151, a catch up mathematics paper for those who have not achieved NCEA level 3. Of the students who had completed a first year statistics paper, the majority, 18 of 28 students, had completed STAT110, which is a biostatistics paper.

There was a relationship between mathematical educational attainment and numeracy assessment scores, with statistically significant differences observed between those who had passed 2nd year or higher papers and each of the other qualification groupings (Figure 4b). However, students who failed the PHSL233 course came only from the groups of students who had completed NCEA level 3 qualifications or first year university qualifications (Figure 4c). None of the course failures came from the group of students who had only obtained NCEA level 2 qualifications or from the group of students who had completed second year university or higher qualifications (Figure 4c).

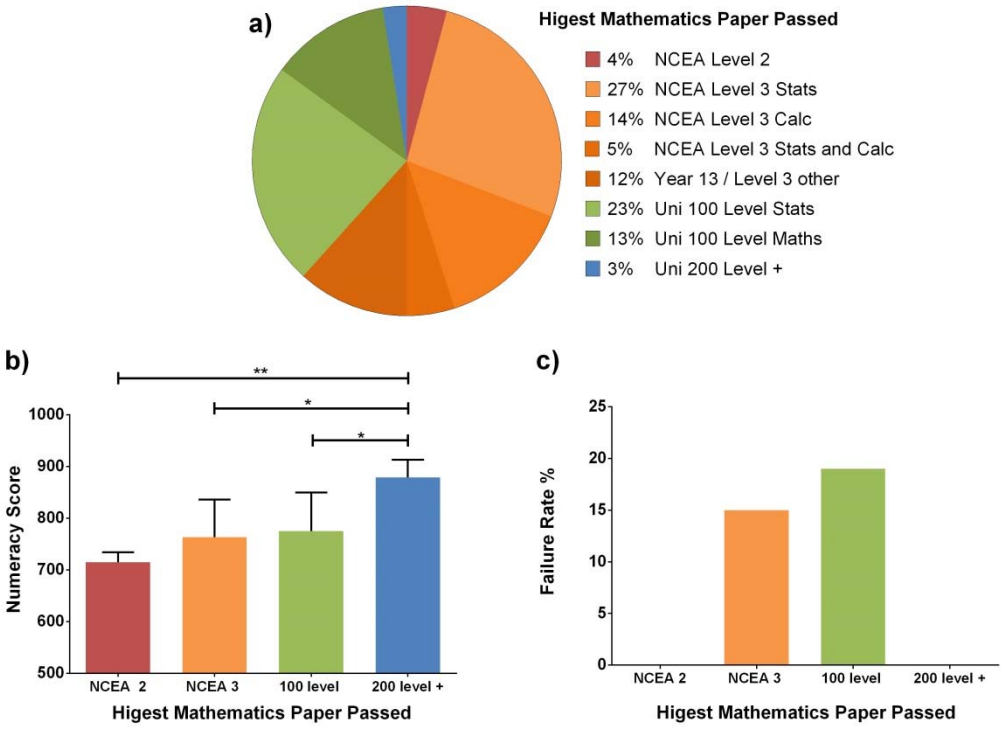

Figure 4. Mathematical education background of the PHSL233 student cohort.

a) Shows the proportion of students in the PHSL233 cohort who have achieved NCEA level 2 (red), NCEA level 3 (orange), first year university (green) and second year university papers (blue). b) shows the relationship between the highest mathematics paper a students have passed and the numeracy score achieved for the TEC numeracy assessment (Mean ± Standard deviation); Statistics is one way ANOVA with Bonferroni's multiple comparisons test* = $P < 0.05$, **=$P<0.005$. c) Shows the relationship between the highest mathematics paper passed and failure rate.

How do students perceive their numeracy?

How do students rate their numeracy?

In the survey, 120 students provided information regarding how they felt about their ability to do the mathematics required for PHSL233, or indicated that they would prefer not to state their ability. Most students gave brief responses, which we categorised into 4 groups for the purpose of analysis: 1) will find it hard, 2) Ok but not great, 3) confident, and 4) very confident. In almost an exact reversal of the TEC numeracy assessment scores, the majority of students rated themselves as being confident (54.6%) or extremely confident (15.7%) with the mathematics required for their course (Figure 5a). Only 7.4% stated they thought they would find the mathematics hard (Figure 5a). There was no relationship between how a student rated their mathematical ability and their actual numeracy assessment score (Figure 5b). However, rating oneself as confident or extremely confident with the mathematics required for PHSL23 was strongly correlated with course failure, with failure rates of 21% and 25% for the confident and extremely confident groups, respectively, compared with an overall course failure rate of 14% (Figure 5c).

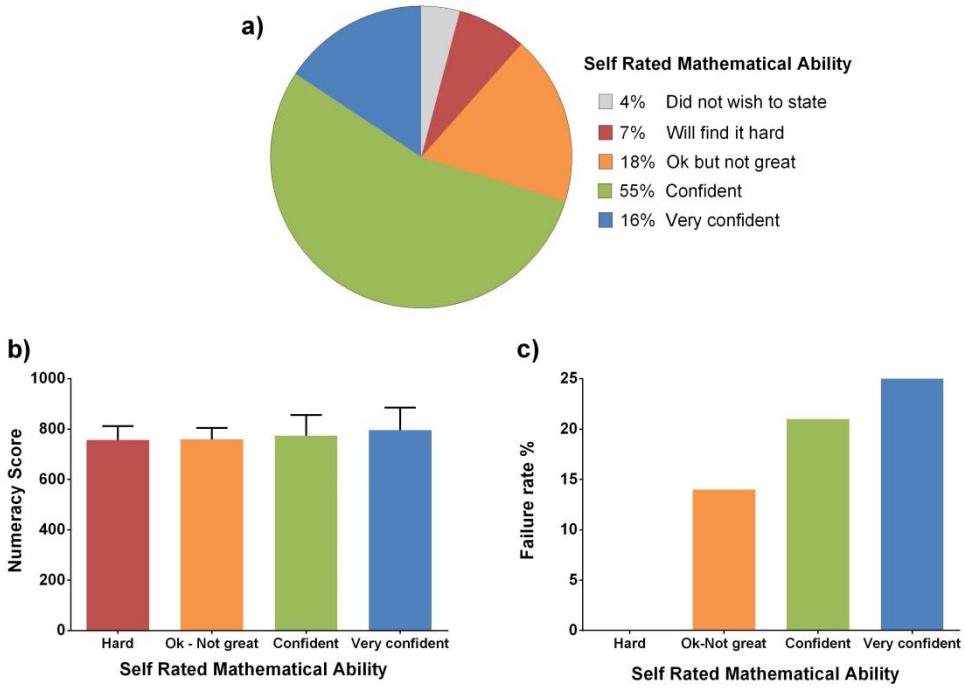

Figure 5. Self-assessed "ability to do the mathematics required for my degree" for the PHSL233 student cohort.

a) Shows the proportion of students in the PHSL233 cohort rated their mathematical ability as will find it hard (red), OK but not great (orange), confident (green) and very confident (blue); grey indicates that a student did not wish to state their ability. b) Shows the relationship between how students rated their mathematical ability and student achievement in the TEC numeracy assessment (Mean ± Standard deviation)); Statistics is one way ANOVA with Bonferroni's multiple comparisons test. c) Shows the relationship between how students rated their mathematical ability and course failure rate.

How do students describe their own numeracy?

In the more detailed responses to our survey we have identified several specific problems that students perceive to have an impact on their ability to perform the mathematical calculations required for PHSL233.

Firstly, a number of students stated that they felt they had previously attained adequate numeracy but that they had forgotten what they once knew. For example, one student stated that:

"I use to know all this stuff but I forgot it when I left high school"

Another student stated:

"It's (my maths is) all right but I'm kind of scared that I forgot how to do some of it".

Students also stated that numeracy revision or practice with mathematics could help them remember or help them link the mathematics they had previously done to the calculations required for physiology. For example, the following comments from the survey:

"I'm a little rusty on the basics but after doing worked examples I have good recall"

"It doesn't come that easily but with lots of practice I can do it."

Students specifically mentioned that they find it hard to understand or manipulate equations and have a poor grasp of basic algebra. Several students indicated that this impacts on their ability to understand physiology as it is taught, particularly in lectures. For example:

"Applying formulas is fine, remembering or deriving formulas is harder. It is easier for me to rote-learn equations than to understand them."

"I can have issues getting my head around equations. It is hard when they are not explained well in lectures."

"I require the equation, and practice before hand is almost essential. If calculus is required I don't feel happy even though I have achieved in calculus."

Furthermore, a number of students indicated that physiology teachers contribute to their misunderstanding of mathematics because they talk about mathematical concepts, or use mathematical language in a way that is unfamiliar to the students.

"I am OK so long as it's not worded weirdly"

"I'm mostly OK when it is explained clearly in lectures."

Preliminary feedback regarding the XOtago numeracy resources developed during this project

Analysis of student usage data indicated that a large number, 131 students of a total of 170 students taking the PHSL 233 course, registered to use the XOtago numeracy resources. Initial results indicate that the numeracy resources may have had an impact on student achievement. There was a large difference in the number of students calculation based questions related to laboratory content correctly in the terms tests. In 2013, 42% of students answered a calculation based question on epithelial resistance correctly and 44% answered a calculation based question on osmotic pressure question correctly, in comparison to 75% and 76% of students, respectively, answered these analogous questions correctly in 2014.

Students were asked to complete an on line survey related to these resources, however as only 9 students responded, these data are not included in this report. The poor response rate was most likely related to the fact that the survey was sent out at the end of the year when students were asked to complete teacher and course evaluation questioners. We asked students for information relating to the numeracy resources in the general course evaluation questioner, 46% of students rated the numeracy resources as extremely valuable or valuable and 60% of students rated the self-test questions as extremely valuable or valuable.

Teaching fellows observed an improvement in understanding and engagement in maths based lab tasks in some PHSL233 laboratory classes. For example, they felt that they spent less time going over total body water calculations during the renal laboratory. This example is particularly interesting because the renal laboratory tasks include a power point presentation that students work through themselves. In 2014, this renal lab power point presentation was adapted to include a click link directly to the worked examples on the XOtago page and a prompt suggesting that students having difficulty with calculations could refer to this. This prompt may have increased the usage of the worked example during that particular laboratory class. Similarly, during the properties of epithelia laboratory, in which students have to perform epithelial resistance calculations. In 2015, we will be able to look at these effects more directly as XOtago will have more advanced user analytics.

Discussion

Who are our students?

The TEC numeracy assessment results indicate that, currently, a majority of our students are functioning above the year 9 numeracy benchmark. However, most students had a numeracy score below 800 and thus are functioning below the level of numeracy we had presumed them to have. As with studies conducted at first year university level (Linsell and Casey, 2013; McNaught and Hoyne 2013; Rylands and Coady, 2009; Tarq, 2002; Wilson, 2013), we observed a correlation between low numeracy and course failure. In the context of learning to solve mathematical problems, our data suggests that most of our 2014 students have mastered a wide range of mathematical rules and procedures and should be capable of emulating or mechanically applying rules to solve problems specific to physiology, provided they are given an adequate guidance. However, we have identified specific areas where students may struggle to understand basic principles, in particular place value, measurement, and algebraic equations.

We did not observe a relationship between the highest mathematics qualification a student had achieved and course failure. However, a majority of our students had not completed a mathematics paper at university level, meaning that it has been 2 years or more since they have studied mathematics. Mathematical skills decline rapidly in the first few years after acquisition if they are not practiced to a high level (Bahrick and Hall, 1991). Thus, the time that had elapsed between studying mathematics in high school and studying PHSL233 may have contributed to our students having lower levels of numeracy that expected. Supporting this, many students stated that forgetting mathematics made it harder to understand what was taught during PHSL233. Of the students who have studied mathematics or statistics at university level, most have taken either MATH151, a paper for those who have not achieved NCEA level 3, or STAT110, a biostatistics paper.

In 2014, changes were made to the New Zealand University Entrance requirements (UE). To achieve UE, students are required to achieve more NCEA credits overall, however the mathematics requirement was reduced to 10 credits at level 1 from 14 credits at level 1 (NZQA website www.nzqa.govt.nz). These revisions to the UE criteria may mean that in the future fewer of our PHSL233 students will have studied mathematics at NCEA level 2 or calculus or statistics level 3, it is also possible that we will see students who have not achieved NCEA level 2. The impact this might have on student achievement and course failure rates are hard to judge based on our data. On the one hand, none of our course failures came from the group who had only achieved NCEA level 2, indicating that these students can make up for lack of mathematical education provided they are aware of their abilities and make use of appropriate resources. On the other hand, reducing the level of mathematics students study could result in an increase in the number of students not meeting the minimum numeracy benchmark or not meeting our previously held presumptions, which in turn could affect failure rate.

Specific numeracy issues and numeracy interventions

Worked examples provide an analogy that learners can emulate during the initial schematic acquisition phase of learning to solve mathematical problems (Ward and Sweller, 1990). As previously stated the majority of our current students appear to have mastered a wide range of mathematical rules and procedures and should be capable of applying these to solve problems specific to physiology. Thus, worked examples are well matched with many of our current PHSL233 learners as a numeracy intervention strategy, provided they are prepared to engage with them. However, our findings also indicate that many students do not understand basic principles relating to place value, measurement, and algebraic equations. This suggests that in addition to resources specific for the calculations, some students may benefit from numeracy resources that revise key concepts from high school mathematics at a much more basic level.

Teaching and revision of basic mathematical concepts such as place value or algebra, is outside the scope of undergraduate science teaching, as it is currently provided (i.e. lectures or laboratory classes). However, this type of support could be presented in extra course resources. For example, in 2015 we will revise the PHSL233 numeracy resources on Xotago to include modules specifically relating to place value, measurement, and algebra in order to provide our students with a revision of these concepts prior to using them in lecture or laboratory teaching. This type of numeracy education could also be provided on a university wide level. For example, the student learning centre could offer short revision courses on basic algebra, or other mathematical concepts. Finally, these issues could be addressed by encouraging all students to taking a revision mathematics paper, such as MATH151, in the first year of their degree.

Comments from students highlighted that the language used when teaching mathematical concepts and calculations in science courses has a strong impact on their ability to understand what is being taught. In particular, the way teachers used presented algebraic equations was identified as being problematic. Teaching at university level tends to be oral and presenter orientated, student understanding is highly dependent on the way lecturers or laboratory teacher's talk about concepts. Algebra is linguistic in that it use letters and symbols to represent objects or quantities and operator symbols (i.e. +, -, ÷, x) are used to describe how these objects or quantities interact, in a similar way words and grammar in language (Burton, 1988). Thus, it makes sense that when teachers use unfamiliar mathematical words or symbols to describe physiological concepts or to explain calculations, students will struggle to understand. When teaching calculations in university science courses, and when designing worked examples, educators should make sure the language and terms they use are related back to those with which the students are familiar. In practice, this could mean that individual teachers might serve their students better if they use language consistent with NCEA. Furthermore, students might be assisted to understand mathematical concepts if departments collaborated to find a consistent way of presenting mathematical concepts in undergraduate courses, rather than using discipline specific language.

Do student perceptions of their own numeracy affect the use of numeracy resources?

Most students in PHSL233 overestimated their ability to do the mathematics required for their course and this overestimation was correlated with course failure. Overestimation of mathematical ability has been identified as a factor in health science students failing to engage voluntarily in mathematical support programs simply because the students who most need help do not recognise that they need it (McNaught, 2013). Helping students understand their actual level of numeracy may significantly affect the number of students engaging with numeracy resources and increase student success.

There are many reasons why students might overestimate their mathematical ability in the context of a specific course; our data suggests two of these are relevant to PHSL233. Firstly, students may not believe that the mathematics required for a course is particularly difficult. Anecdotally, there are some students who appear to have selected physiology as a major because there is not a mathematics pre-requisite and they think it will be easier that other courses. Secondly, students may not have good understanding of their current levels of numeracy. In the case of PHSL233, this may be related to students forgetting mathematical skills. Numerous students made comments about forgetting maths and the majority of our students have not studied mathematics since year 13, two or more years previously.

While we initially used the TEC numeracy assessment as a research tool, we are aware of its potential as a tool for addressing the discrepancy between a student's actual mathematical ability and their perceptions of their ability. In 2015, we will use the student's TEC numeracy score to identify students who need extra help and to direct students to numeracy resources. We intend to inform students that in PHSL233 a scores above 800 are ideal. Numeracy testing could also be used at a departmental or university wide level, perhaps organised through student support services such as the student learning centre, perhaps in conjunction with short revision courses relating to basic numeracy concepts.

Bullet points of suggestions based on this research project

For individual teachers

- Do not use equations alone to explain scientific concepts. Use visual or descriptive explanations to describe concepts and link the concept to equations.
- Integrate written, visual, or audio-visual explanations with worked examples; do not present the calculations and explanations separately.
- Divide calculations into steps rather than providing a continuous worked example.
- Describing mathematical concepts using language modelled on the high school curriculum might be more effective than using discipline specific language to describe mathematical concepts to students.
- Provide students with worked examples before you use equations in lectures or labs so students are familiar with them.
- If you expect students to use calculations, provide practice questions with fast feedback.

At Department and University level:

- Departments could collaborate to find a consistent way of presenting mathematical material in undergraduate courses, rather than using discipline specific language. This is particularly true in first year courses where students are still aiming for diversity in their learning rather than specialisation.
- Students need to be more aware of their own numeracy. Departments, or the university as a whole, could assist with this by providing numeracy testing that is independent of specific courses and unrelated to mathematical pre-requisite courses.
- Provide assistance, such as short courses revising basic numeracy concepts, via student support systems such as the student learning centre.

Future work

One significant impact of this project is that it has allowed us to establish the infrastructure required to replicate this study with the PHSL 233 students in subsequent years, and to collaborate with related departments in order to study numeracy in other student groups. Two significant projects are already underway in this regard.

Firstly, in 2014 the criteria for achieving university entrance were changed. In 2016 students who have achieved university entrance under these revised criteria will be studying PHSL233. We will repeat this study with the PHSL233 student group over the next 3 years in order to track the effect of these revised university entrance criteria on numeracy and performance in PHSL233.

Secondly, because of this work, Toni-Ann Alsop has established collaboration with the school of pharmacy, in 2015, she will be involved in a project to investigate the numeracy of pharmacy students, and how they perceive numeracy in relation to their education and future career.

References

Bahrick, H., and Hall, L., (1991). Lifetime maintenance of high school mathematics content. *Journal of Experimental psychology: general*, 120 (1), 20-33.

Burton, M., (1988). A linguistic basis for student difficulties with algebra. *For the learning of mathematics.* 8 (1), 2-7.

Byrnes, P., (1992). The conceptual basis of procedural learning. *Cognitive development,* 7, 235-275.

Carraher, T., Carraher, D., and Schliemann, A., (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology*, 3, 21-29.

Chandler, P., and Sweller, J., (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology,* 62 (2), 233–246.

Coben, D., (2003). *Adult Numeracy: Review of research and related literature.* London: National Research and Development Centre for Adult Literacy and Numeracy. (http://nrdc.org.uk/publications_details.asp?ID=35)

Cooper, G., and Sweller, J., (1987). The effect of schema acquisition and rule automation on mathematical problem-solving transfer. Journal of educational psychology, 79 347-362.

Dunning, D., Kruger, J., (1999). Unskilled and unaware of It: How difficulties in recognizing one's Own incompetence lead to inflated self-assessments. *Journal of Personality and Social Psychology*, 77(6), 1121-1134.

Evans, J., (2000). The transfer of mathematics learning from school to work, not straightforward but not impossible either. In: A. Bessot and J. Ridgway (Eds.), Education for mathematics in the workplace. Dordrecht, NL: Kluwer Academic Publishers.

Kirschner, P., (2006). Why minimal guidance during instruction does not work: An Analysis of the failure of constructivist discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75–86.

Linsell, C., Anakin, M., (2012). Diagnostic assessment of pre-service teachers' mathematical content knowledge. *Mathematics Teacher Education and Development*, 14(2), 4-27.

Linsell, C., Casey, C., (2013). Undergraduate numeracy in the Business School. *Proceedings of Spotlight on Teaching and Learning conference, 26th-27th August 2013.* Dunedin: Otago University. (http://spotlight.otago.ac.nz/files/2013/08/Final_spotlight_booklet_web.pdf).

McNaught, K., (2013). When a mathematics support pilot program fails miserably: Looking for answers. In: Steinle, V., Ball, L., and Bardini, C., (Eds.), Mathematical education: Yesterday, today and tomorrow (Proceedings of the 36th annual conference of the Mathematics Education Research Group of Australia). Melbourne, Victoria.

McNaught, K., Hoyne, G.T., (2013). Testing program reveals deficient mathematics for health science students commencing university. *Issues in Educational Research* (*Special issue: Teaching and learning in higher education*), 23 (2), 180 – 195.

Ministry of Education, (2014). Tertiary education strategy 2014-2019. (http://www.minedu.govt.nz/NZEducation/EducationPolicies/TertiaryEducation/PolicyAndStrategy/TertiaryEducationStrategy2014-2019.aspx)

Rylands, L.J., Coady, C., (2009). Performance of students with weak mathematics in first-year mathematics and science, *International Journal of Mathematical Education in Science and Technology*, 40(6), 741-753.

Simon, M., (1995). Reconstructing mathematics pedagogy from a constructivist perspective. *Journal for research in mathematics education*, 26, 114-145.

Schneider, M., and Stern, E., (2010). The developmental relations between conceptual and procedural knowledge: A multimethod approach. *Developmental Psychology*, 46(1), 178-192.

Sweller, J., (1994). Cognitive load theory, learning difficulty and instructional design. *Learning and instruction*, 4, 295-312.

Tariq, V. N., (2002). A decline in numeracy skills among bioscience undergraduates. *Journal of Biological Education*, 32(2), 76-83.

Tertiary Education Commission, (2008). Learning progressions for adult numeracy. (http://www.literacyandnumeracyforadults.com/resources/354913).

Thompson, K.V., Cooke, T.J., Fagan, W.F., Gluck, D., Levy, D., Nelson, K.C., Redish, E.F., Smith, R.F., and Preston, J., (2013). Infusing quantities approaches throughout the biological science curriculum. *International Journal of Mathematical Education in Science and Technology*, 44 (6) 817-833.

Van Gog, T., Paas, F., and Van Merrienboer, J.J.G., (2004). Process-orientated worked examples: improving transfer performance through enhanced understanding. *Instructional Science*, 32, 83-98.

Ward, M., and Sweller, J., (1990). Structuring effective worked examples. *Cognition and Instruction* 7 (1), 1–39.

Wilson, T.M., (2013). Exercising QS: Quantitative skills in an exercise science course. *International Journal of Mathematical Education in Science and Technology*, 44(6), 796-807.