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17. CONCEPTUAL INTERSECTIONS:

Re-viewing academic numeracy in the tertiary education sector as a threshold concept

INTRODUCTION

Tertiary educators expect that students have developed sound numeracy skills from their previous studies in mathematics and that they are able to transfer and apply these skills to their studies in other discipline contexts, such as the life sciences. In reality, each year a proportion of our students fail to meet this expectation. The "maths problem" persists despite resources being directed to improve levels of academic numeracy. It is important to note that there is a requirement to complete mathematics prior to and/or as part of their degrees in life sciences and in medicine. However, the simple mathematical operations of multiplication and division addition and subtraction remain problematic for a significant subset of students. There is likely to be a raft of factors that underpin this maths problem and here we are considering only a few. This maths problem prevents students from embracing the quantitative dimension of the life sciences. The relevance of undertaking a quantitative approach to gain a better understanding of a biological phenomenon is lost on some students particularly if the calculations involved are perceived to be impenetrable. So, rather than witnessing numeracy as a "transferable skill", we see students transferring their maths anxiety i.e. "a transferable anxiety"; commonly expressed as "*I can't do maths*". Instead of our students seeing the relevance of numeracy to their studies in the life sciences, subjects such as mathematics and statistics are perceived as unconnected to their discipline, and therefore "*maths is boring*". Student comments: "*I can't do maths*", and "*maths is boring*" exemplify rigid standpoints, standpoints that we need to challenge if we are to aid students to enter their liminal space. Both of these standpoints speak to our students' prior conceptions of a subject which has been highlighted as important (Biggs, 1989).

Our focus is at the point where students stumble as they practice academic numeracy in the life sciences and medical statistics. We are concentrating on the moments when students withdraw from learning at the point of entering their liminal space, as described by Meyer and Land (2003, 2005) and further examined by Savin-Baden (2008). An obvious indicator of when students have disengaged in a class is when they fail to make eye contact. For instance, this occurs when one begins to shift from describing a biological phenomenon in words to presenting a mathematical abstraction of that same phenomenon (e.g. an equation, or data points

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tabulated or graphed). A grasp of numeracy is essential to understand the abstraction of the biological phenomenon; failure to appreciate that patterns in biology can be represented in abstracted mathematical forms inhibits students' understanding of scientific practice.

REEXAMINING OUR PRACTICES AS SCIENTISTS AND IN TEACHING SCIENCE

As scientists we examine the patterns in our discipline; we observe phenomena and assert hypotheses about phenomena. In our attempts to explain the world, we test our hypotheses by conducting experiments using the hypothetico-deductive method almost exclusively. Experiments need to be undertaken in accordance with this method, requiring a sound understanding of the parameters being measured, and of when and how to measure and record the important data. The conduct of the experiment needs to be coupled to an understanding of the aims of the study and its limits and feasibility. Scientists are expected to be confident with their practice.

So how does this description of scientific method relate to student learning in science? Many undergraduate practical classes provide opportunities for students to observe like a scientist, and then to record the observed data. It is, however, rare that the raw data will be the final data, particularly numeric data. Data sets may need to be clustered, units of measure may need to be converted, and control data need to be accounted for. Formulae may need to be applied to determine statistical significance. Also, when presenting the results, the patterns within the data need to be displayed clearly. Students often attend practical classes unaware of these underlying procedures. Rather, they arrive under the impression that they will be presented with a dull data-handling or statistics practical that they perceive to have no relevance in their future career. Asking students to learn how to observe and explain like a scientist is one of the "underlying games" in life science teaching practice; being more explicit about what we expect students to do, resonates with Taylor and Meyer's work on how biologists work i.e. the testable hypothesis as a threshold concept (2008).

We present an experiential learning cycle in science that mirrors our practice of attempting to understand biological phenomena (Figure 1) (Quinnell and Thompson, 2008; LeBard and Quinnell 2008). We have mapped on this cycle where numeracy and literacy skills are required. Process A is focused on calculations and involves making observations, recording raw data, processing this data into evidence which is represented mathematically. Process B is where the experimental evidence is placed in the disciplinary context and involves describing and explaining the patterns evident in the data. We have indicated some of the points where students appear to uncouple themselves from this process: As part of the experimental process (Process A) students are expected to: (1) understand the relevance of participating in the process, and to participate by, (2) make scientific observations of a scientific phenomenon, (3) record the required data, (4) process the raw data and, (5) translate these data into evidence by clustering the data to generate figure, table or equation that make the patterns in observations evident. Process B is translating the data summary into a scientific explanation and involves: (6) describing the patterns in the data and the relationship between data sets and (7) making critical statements about how well these data support, or refute, the premise (or hypotheses) upon which the observations were made. We have indicated some of the points (thick black arrows) where we observe student engagement wane: i) failing to see relevance at the outset, ii) experiencing maths anxiety, iii) not understanding the computational processes, iv) not being able to describe the patterns in the data in words, and v) not being able to relate the results to the original aim. This diagram can be mapped onto the experimental component of the scientific method; we are dealing with science learning that is common to both students and practitioners of science.

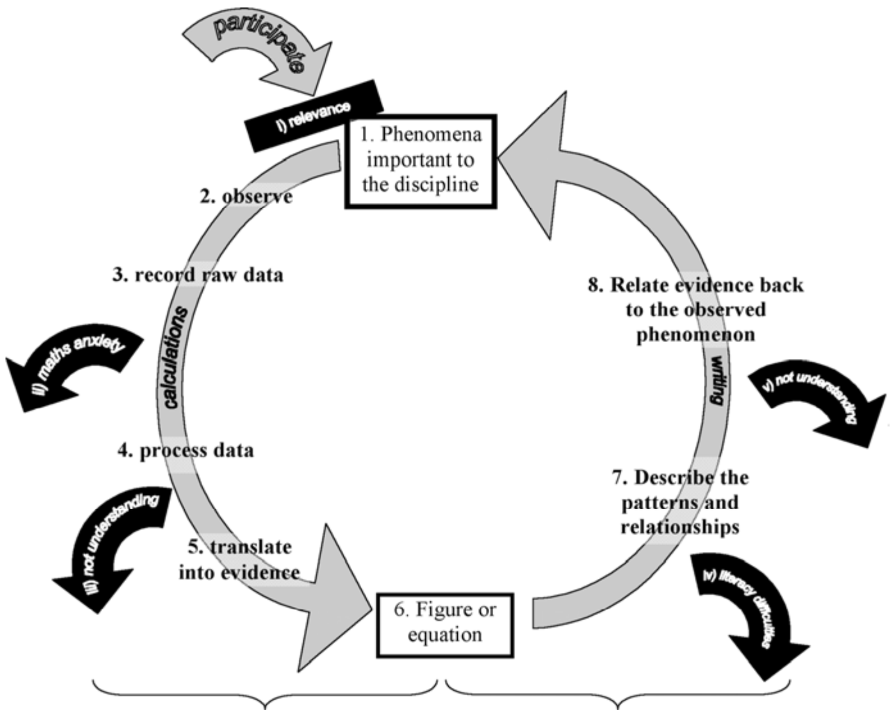

Figure 1: Generalised process in undergraduate science practical classes

A. Experimental process: translating observations into data summary

B. Interpreting process: translating evidence into an explanation

In Figure 1, the black arrows indicate the moments when students experience obstacles to learning. These obstacles are not identified as being exclusively around threshold concepts but appear to be at points where concepts are linked and where numbers play a major part. We have begun to map these obstacles onto this generalized model of scientific method; the movement from observing scientific phenomena to the process of representing those phenomena in abstracted form (Figure 1 Process A). In medicine, the same uncoupling of student learning is seen when the students are required to translate these abstracted forms back into a concrete explanation of the phenomena (Figure 1 Process B). This is apparent in the interpretation of epidemiological figures or the results of clinical studies, for example. The obstacles shown in the Figure 1 are not exclusively caused by numeracy issues but we argue that they all are modulated by numeracy skills. The importance of this seems small initially as students in our classes are those who have achieved a high grade in at least level 3 Mathematics at the Australian final year (year 12) school examinations (the HSC). This is an above average level of attainment, yet a significant number of the students still have a problem with manipulating and interpreting numbers that can precipitate discomfort and even anxiety within the classroom (Ben-Shlomo, Fallon, Sterne and Brookes, 2004; Tariq, 2007). The term “numerophobia” was coined for this phenomenon by Ben-Shlomo et al, (2004). This is a fear of using numbers that tends to occur more with interpreting formulae, working out equations and basic mathematical manipulation (Klinger, 2004; Quinnell and Wong, 2007; Moss, Greenall, Rockcliffe, et al., 2007). Numerophobia initiates a strong emotional response that can overwhelm the student so that their work is compromised. In lectures, a wider effect of this can be seen when students react en masse by a communal sigh or exclamation followed by disengagement when a PowerPoint slide accompanying description of formulae or equation is displayed. Students in some disciplines may be able to get by with limited mathematic involvement, but medicine and life sciences have a surprising amount of formulae, equations and mathematical explanation that are essential to the students’ progress. For example, patterns of populations are expressed in statistical parameters and the patterns of physiology are expressed in the parameters of physics.

So where does that leave us with student numeracy? What is it that we want students to make sense of, and be critical of, when they are “doing calculations” in these disciplines? How does student confidence affect competency? Can strategies to improve student numeracy be created by re-viewing and deconstructing the problem and therefore discover the threshold concepts buried within academic numeracy obstacles? We sought answers to these questions and present our findings in the following case studies, one in medical statistics and one in biology. Two solutions are presented: the first proposes teaching numeric concepts without the numbers; the second proposes addressing student confidence as a mechanism to reduce transference of students’ maths anxiety across to science.

PRESENTING NUMERIC CONCEPTS WITHOUT THE NUMBERS

Unpicking statistical concepts

Teaching medical students statistics relevant to their future practice is hampered in two ways. Firstly, because it is a “Cinderella” subject; statistics is far less glamorous or medical than the disciplines and topics of anatomy and physiology and so on (Altman and Bland, 1991; Sinclair, 1997). Secondly, it is perceived to involve mathematics and numbers and hence is often viewed by students as difficult, complicated, unpleasant or just plain boring. Consequently at UNSW in 2005, we strove to make a medical statistics course (embedded within an evidence-based medicine element in the new undergraduate medical curriculum) as relevant as possible to clinical practice. Following a poor result in the first formative examination of this course in 2005, several points of student disengagement were identified in the mainly online mode of learning environment. We re-viewed the content and teaching methods with the aim of finding a more engaging and successful way to approach teaching these topics. Threshold concepts as proposed by Meyer and Land (2003) seemed to fit some of these obstacle points perfectly. As Meyer and Land state in their original paper on this topic, a threshold concept:

> ...represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress (ibid, p.1).

In statistics there are few publications that discuss threshold concepts, but, over ten years ago, Kennedy (in a paper on learning and economics) noted that students of statistics could carry out appropriate statistical exercises adequately but fail to understand the “big picture” (Kennedy, 1998). He proposed an elegant reason for this:

> What they are missing is the statistical lens through which to view the world, allowing this world to make sense. The concept of sampling distribution is this statistical lens. My own experience discovering this lens was a revelation, akin to the experience I had when I put on my first pair of eyeglasses – suddenly everything was sharp and clear (ibid, p.142).

The sampling distribution is the distribution of all the possible sample means for a variable taken from one population or set of values. Arguably, it is fundamental in understanding how statistics work as it is the basis of inferential statistics. In describing his own experience, Kennedy suggests that understanding the sampling distribution provides a statistical “lens” through which the rest of statistics becomes clearer. We assert that this meets a key characteristic of a threshold concept according to Meyer and Land (2003, 2005): that is, that it is transformative. Once students understand the sampling distribution, they approach statistics in a different way; less that this is a mathematical process, and thinking more as a statistician would. This is similar to the way in which Shanahan and Meyer (2005) suggest that students studying economics learn “to think like an economist”. This transformation is usually irreversible and enables the student to understand other troublesome concepts that are based upon this essential premise.

On examining sampling distribution in more depth one sees that the concept is not only transformative and likely to be irreversible but that it contains troublesome knowledge and language, and also is integrative. Detecting troublesome knowledge and language in statistics is not difficult. Those of us who are non-statisticians will still remember how impenetrable the language was on first learning statistics (our peers calling it “gobbledegook") and even more worrying were the mystifying concepts that seemed to tie one's brains in knots, over and over again. For instance, central tendency (the measurement of average and dispersion) is a common stumbling block, but is essential if one is to understand the concept of sampling distribution. It may be troublesome as there are several measures of central tendency, useful with different distributions. Also, one has to understand distributions, symmetry, skewness (which can be rather tricky and counter-intuitive) and dispersion (which involves the derivation of several more confusing formulae and itself requires a tacit understanding of measurement and spread). Additionally, statistical language itself can be difficult and often heavily mathematical. Even in encountering the seemingly easier concept of central tendency, a student will come across: “sum of squares”, “degrees of freedom”, “variance” and “deviations from the mean”. Furthermore, the concept of sampling distribution integrates several basic statistical concepts (along with their derivations and formulae) such as: population, generalizability, sampling, randomisation, distributions, central tendency, estimation, sampling error, and standard deviation.

So, in statistics, the example of sampling distribution is relatively easy to identify as a threshold concept; Kennedy's wonderful visual metaphor identifies this is an essential key to “thinking like a statistician". One could argue that the whole of inferential statistics hangs on this premise, so that a failure to understand this would be a hindrance to comprehending this area of statistics. On the other hand, a deep understanding of the sampling distribution leads a student to survey the whole aspect of statistical practice in a different light. The whole curriculum can be viewed through the “statistical lens” as described by Kennedy (1998). This lens then allows a plethora of other concepts and new practical applications to become apparent and be approached by the student with a better degree of understanding.

To identify other threshold concepts in our teaching of statistics to medical students at UNSW, we followed Eckerdal, McCartney, Moström, Ratcliffe, Sanders et al's (2006) proposal of approaching this by first listing all the core concepts taught in the content. This is their “breadth-first” approach that proposes that among these listed concepts will be some threshold concepts. Simultaneously, the evaluations and feedback received from students were examined in order to identify where they felt that they were stumbling. This information was then analysed with the characteristics of threshold concepts in mind (Meyer and Land, 2003, 2005). To identify whether there is troublesome knowledge and language in the concepts, they were *unpicked*; stripped back to their fundamental elements. Added to this were the experiences of the teachers in their own learning of these concepts and experiences of teaching these concepts. In looking at our own learning we were able to identify the points where we struggled, faltered and failed (Bonner, Harwood and Lotter, 2004).

Two other overarching threshold concepts were identified in this manner (see Figure 2): the “Strength of evidence lens” (centred around hypothesis testing and statistical significance) and the “Applicability lens” (centred around the applicability of evidence). This third threshold concept was identified with assistance from Mayer (2004) who has deftly unpicked this area, clarifying the application of evidence in a clinical situation for the practitioner. These overarching threshold concepts are not intended to be placed in any order, for instance, most statisticians and epidemiologists would discuss hypothesis formation before sampling. All three of these lenses overlap so that some concepts are found within more than one “lens” and unsurprisingly, these lenses integrate other theories, for instance: Bayesian theory and probability (both likely candidates for threshold concepts as well).

Threshold Concept a) Kennedy's (1998) - "Sampling distribution lens"

– Sampling and sampling distribution
– Sampling error
– Randomisation
– Central tendency
– Central limit theorem and Normal distribution
– Other continuous and discrete distributions, including t and chi squared
– Regression to the mean

Tacit knowledge required / allied concepts: types of data; frequency distributions; study designs; placebo effect

Threshold Concept b) Statistical significance –"Strength of evidence lens"
Hypothesis formation and testing:

– Null and alternative hypothesis
– Effect size
– Statistical testing
– P values and significance
– Confidence intervals
– Type 1 error
– Power and Type 2 error
– Research design and validity
– Strength of evidence criteria

Tacit knowledge required / allied concepts: understanding how statistical distributions convert into statistical significance tables; and Probability (and Bayesian theory)

Threshold Concept c) Applicability of evidence – "Applicabilty lens"

In medicine / health this is clinical significance = peculiar to medical / health statistics and can be thought of as "applicability" (Mayer, 2004):

– Best evidence
– Clinical evidence
– Patient values
– Clinical situation

Figure 2. The three main overarching threshold concepts in statistics with the associated basic and threshold concepts that underpin them

We acknowledge that the interaction of these concepts is highly complex as they integrate many basic and threshold concepts. The learning of basic concepts is recognised as "basic conceptual changes" as described by Davies and Mangan (2007, 2009). They are not transformative concepts in themselves but contribute to the "discipline conceptual change" of the threshold concept (ibid). Clearly, a student might understand all of these basic concepts separately but still may not be able to grasp the full threshold concept. Practical application of these concepts helps the student to understand them more fully, especially if applied with what Davies and Mangan (ibid) dub "procedural concepts". These concepts "provide the means by which the structural form of the [threshold concept] portal can be assembled (Davies and Mangan, 2009). They allow the "discipline conceptual change" (threshold concept) to be understood by organising the concepts in a modelling process. This interaction between concepts feeds back until the students' understanding "deepens" to the transformative point (ibid). Examining statistics with this theory has assisted in unravelling the links between the concepts. Furthermore, we concur with Davies and Mangan (ibid) that the identification of procedural concepts will assist in the development of better teaching and assessment methods.

Unpicking numeracy issues

We propose then that these threshold concepts are built up of the basic concepts listed below them. Some of these might be threshold concepts in their own right and are themselves informed by several other concepts of an even more basic level. In unpicking all of these concepts, it becomes obvious that they contain some basic numerical processes (e.g. summation, equations and ratios) and also a great deal of basic probability theory. Subsequently, numeracy skills are extremely useful in navigating the mathematical and probability language used in explaining and deriving the formulas for these concepts. A student who has poor numeracy skills or numerophobia could fail to learn many basic concepts in statistics and then would be more likely to flounder in understanding the threshold concepts. On the other hand, students who like numbers and understand probability are likely to have a much easier ride through the liminal process as described later in this chapter.

A mapping exercise is being undertaken to reveal the networking of all of these concepts and to see how they map onto the overall learning cycle in Figure 1. This process is already revealing that there is a close interlinking of the basic and threshold concepts. It shows that there is a possible natural progression in terms of teaching from one threshold concept to the next. This is not surprising in terms of the manner in which inferential statistics originated but is surprising when one analyses the established methods used to teach it. Standard text books (for medical statistics) do not seem to agree on a particular order of learning these concepts, although most have chapters devoted to the threshold concepts identified above in Figure 2. However, they are not explicitly identified as threshold concepts, nor are the links between these concepts identified or emphasized in a consistent way. Interestingly (though uncorroborated), from our own experience, the better statistics courses that we have encountered were those where teaching was focused on these specific areas and progression between them was mapped and described. We would argue that by identifying these threshold concepts we have found another way to observe and analyze how students learn statistics and hence can target our teaching.

With these threshold concepts identified, the next step to unpicking the difficult learning areas was to identify the numeracy issues underlying and making up the threshold concepts and to examine this in terms of student learning and our teaching approaches. Bulmer, O'Brien and Price (2007) have carried out a detailed online evaluation of 555 biology students being taught basic statistics. One of their aims was to begin to identify the content areas that students considered most “difficult to learn”. They found that a frequent issue raised was to do with numeracy: “Maths/Formulas” and choice of “Tests". In examining the basic content taught to our medical students, numeracy was also identified as being of key importance in all of the statistical threshold concepts and student feedback commonly mentioned maths or numbers as being a problem (Thompson 2008). Bulmer et al. (ibid) further suggest that the derivation and application of concepts is more important to student learning than actual mathematical skills. Students are able to do the maths but cannot apply this to the content or in the application of the content. Davies and Mangan’s (2009) procedural concepts may be of vital importance here in explaining how these learning processes occur or are hindered.

Traditionally statistics, even when taught in non-mathematical disciplines, is taught through the formulae and equations that represent the statistical concepts. It is standard practice to derive or present the formulae as part of the explanation of an important theory, concept or statistical test. However, for the numerophobic, this can present an insurmountable challenge due to the anxiety that this provokes. This anxiety may result in a misunderstanding or complete failure to understand. Further study on our part and Bulmer, et al (2007) has shown that the students fail to apply the statistical techniques correctly, which is a failure of application:

> So while the students do not find the underlying mathematics knowledge to be challenging or particularly “threshold” in nature, the conceptually difficult bridge to traverse appears to be in the selection and application of statistical techniques within relevant contexts (ibid, p.13).

Do students who are just beginning to understand a threshold concept, entering into that *liminal space* of learning and preparing to cross a *learning bridge* (Savin-Baden, 2008), falter and fail to cross the final threshold due to inability to understand the formulaic explanation or the numerical calculation that is inherent in the explanation? Does the discomfort experienced and the fear of numbers and equations cause confusion and disengagement that forces an affected student to back out of the liminal space (Savin-Baden, 2008)? If so, this leaves the student with only a partial understanding of the concepts involved and interrupts the transformative process that will lead the student into a higher level of understanding or practice as described early on in threshold concept research by Meyer and Land (2003). This failure to engage fully with the concept may also leave them with a lack of confidence in learning this particular content and may even initiate a full blown aversion.

To overcome this problem in a mainly online teaching environment (which has its own limitations when it comes to engagement and knowledge transfer) we chose to target the mathematic formulae by presenting them in a less mathematical way than previously and with an emphasis on functionality, theory and application. The main aim in teaching evidence-based medicine and basic statistics at this early stage of the undergraduate medical program at UNSW is to develop the students’ ability to interpret results and apply this clinically; the learning skills targeted by the course are the interpretation of results which includes mastering and understanding of statistical tests, statistical significance and clinical significance.

This process is depicted in the second half of the cycle shown in Figure 1. What can be seen from this figure is that there are places where numeracy holds the key to understanding and so this is where an effort was made to analyse the concepts further in order to develop parallel but non-numerical explanations. To support those students who could not approach statistical formulae, visual and narrative explanations were expanded and developed. For example, the difficult threshold concept of the central limit theorem (in the Sampling distribution concepts, Fig. 2) is usually explained in terms of formulae and complex graphs, however, we also taught this using a narrative example of sampling in order to describe it and a picture to visually impress this further (Figure 3).

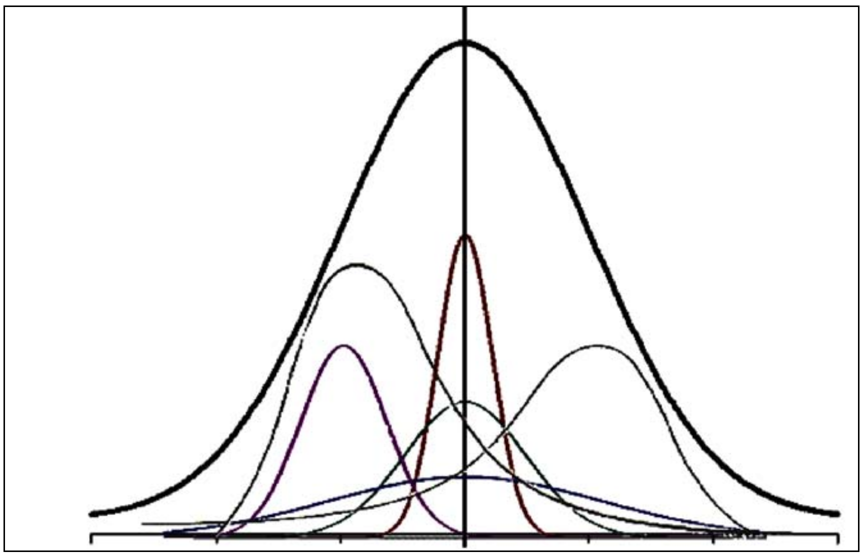

Figure 3. Example from an online statistics tutorial. This is the final figure of a series depicting the distribution of the means of samples (central narrowest distribution) used to explain the central limit theorem. A definition and questions with detailed explanations sit adjacent the figure series.

Furthermore, lectures are now targeted at explaining the threshold concepts and the underlying basic concepts underlying them using both maths and non-math based approaches. More face to face tutorials are provided in the course: an increase from three to ten practical classes (over the first two years of the medical program) with tutors on hand to advise as students attempt the exercises in the online tutorials and whole class discussion of key points. This change has been appreciated by the students; there has been a good response from both informal and formal feedback (Thompson, 2008). By offering several "variations" of the same content to a student in terms of perceptive modalities (narrative, visual and mathematical), the improved tutorials, practical classes and lectures are providing a richness of perspectives or different views, of numeric concept (Dienes, 1959 cited

Meyer, Land and Davies, 2008) and in doing this the student is better prepared to traverse and reach the bridge of liminality and eventually cross the threshold for this concept (Savin-Baden, 2008).

Evaluation of these improvements to the online tutorials is continuing and will be described elsewhere. However, preliminary evaluation has shown that the students are completing the online tutorials in higher proportions and are showing an improved understanding of the key assessable elements around the threshold concepts of Strength of evidence and Applicability (Figure 2). There were students who still found these examination questions difficult but more passed these than previously and overall the students appeared to have a better grasp of the threshold concepts: less than 15% of the students failed the short answer questions after the changes (2007-8), compared to over 30% in 2005, the mean average mark increasing by 7%. On the other hand, the qualitative tutorial feedback revealed that there were a few students who would like more mathematical explanations: one student suggested “More maths-background behind each of the explanations!” (Thompson, 2008). These could be dubbed the “numerophilic” students; those who find that mathematics and formulae are the best way for them to understand these troublesome concepts. In contrast, the numerophobic students appear to prefer the narrative, visual or written styles of learning and maybe the best way for these students to cope with the formulae and these troublesome concepts is to understand it fully this way first. One student felt most distanced in a module “when numbers are brought in” whilst another found that an “illustration on odd ratio is clear” (Thompson, 2008). Concurrently, Freeman, Collier, Staniforth and Smith (2008) have carried out similar improvements to their medical statistics course at the University of Sheffield, UK. Although not focussing on threshold concepts as such, they concentrated on teaching basic statistical concepts with less emphasis on requirement for inherent numeracy skills and using “materials… created that presented the same information in a number of ways, maximizing the opportunities for students with different learning styles and approaches” (ibid, Methods section, para. 3). Their evaluation of this particular improvement showed a statistically significant increase in understanding of definitions of basic concepts but, interestingly, not for the question: do you “Feel comfortable with the basics of medical statistics”? (ibid).

In summary, our first case study shows that students are struggling with the numeracy within troublesome concept areas. In bypassing the numerical explanation initially we have helped them to enter the liminal space with less anxiety and more readily achieve understanding of the basic and threshold concepts in statistics. The overarching threshold concepts of Sampling distribution, Strength of evidence and Applicability of evidence (Figure 2) were identified and ways of explaining them without an emphasis on numbers were developed and implemented. These concepts were then more easily grasped by students and in so doing they were more able to process the information presented to them in epidemiological studies and in clinical trials (Figure 1, Process B – evidence interpretation). The barriers to understanding and interpretation were lifted by reducing the exposure to this numerophobic problem. By removing the need to explain the concepts using numbers, the anxious environment that these numbers and formulae had caused in the liminal space cleared and the numerophobic students were able to find another route through this difficult learning moment. These students describe how they are then more readily able to approach the numerical explanations and understand them more fully.

HOW ARE CONFIDENCE AND ABILITY LINKED WITH RESPECT TO ACADEMIC NUMERACY?

The link between student confidence and their numeric abilities when studying science is beginning to be explored. Current findings highlight that there is a lot that we do not understand about the role of student confidence in applying their numeric skill when learning about science. Klinger (2004) has identified that a proportion of students who are not engaging in numeric tasks within the context of science are maths anxious and that these students are at risk of failing or withdrawing from university. Because engaging constructively with available course resources (whether these are online or resources offered more traditionally) is required for success in a course, the issue then becomes how to assist those students who are not engaging with these resources because of their anxiety and to explicitly address student confidence.

Having spent many months designing a series of online modules to assist students with the calculations involved in their plant physiology practical work, the lack of engagement with the numeric content of biology persisted after these online modules were implemented. Although most students used the numeracy modules and found them useful for consolidating their understanding, there was still a percentage of students whose difficulties with calculations persisted (Quinnell, May and Lloyd, 2004). The inference here is that the online "how to" guides seemed to not solve the maths problem for all students; not all students were able to engage meaningfully with these and did not use the modules to improve their numeric proficiency (Tariq, 2007; Quinnell, 2006).

Furthermore, most online learning systems seem to lack the capacity to interrogate students about their confidence at the point of undertaking data analysis. In a face-to-face tutorial, which the online modules were designed to replace, it is possible to *read* the student, and student body language is powerful feedback for tutors. To linger at those moments when the students *break eye contact* (the "*look away"* moments, which we see as being an indication that a "threshold" has been reached) and to modify tutorials and lectures in response to this, is a powerful teaching strategy, that to our knowledge, has not been replicated in the online learning environment.

As a result of these findings our teaching strategy was modified. Face-to-face tutorials were re-introduced and constructed around a numeracy diagnostic focused on confidence. The aim of this diagnostic was to pinpoint where numeracy was problematic and where students were uncoupling themselves from the learning process (Quinnell and Wong, 2007). This diagnostic was designed and implemented in a second year undergraduate plant physiology course. The vast majority of students have completed both first year mathematics and first year chemistry as prerequisites for entry into plant physiology. The diagnostic task was implemented at the start of the semester and allowed each student to determine their confidence: (a) with articulating their understanding physical parameters used in physiology, (b) with understanding the units of measure of these parameters; and, (c) in their ability to calculate and convert between units of measure. For many students this was the first time their discomfort and their lack of confidence with calculation was acknowledged in a practical class task. Enabling students to address their discomfort and engage in their own skills development has proved to be a useful approach, particularly for students lacking confidence (Quinnell and Wong, 2007). In this study those students who had the highest engagement with the task were those with the least confidence in their responses. This diagnostic has proved to be valuable to academic staff and initiated a dialogue about course expectations that included a discussion on skills development.

The literature shows that even students of mathematics have anxiety when studying maths (e.g. Meece, Wigfield and Eccles, 1990; Phan and Walker, 2000); these studies provided an important starting point to understand maths anxiety in a discipline other than mathematics (Klinger, 2004; Tariq, 2007). One of the main tasks that we expect students to carry out is to recognise data sets or clusters of data that logic dictates relate to each other (Figure 1, Steps 2 – 5). But how are students expected to focus on the biological principles in practical class when confronted with the relatively complex measures such as one used for the rate of photosynthesis: mol O_2. s^{-1}. mg^{-1} chlorophyll? In this example, students are required to measure the change in concentration of oxygen dissolved in the buffer solution containing photosynthetic plant tissue or algae using an oxygen electrode; the units of measure recorded by oxygen electrode are mM O_2. min^{-1}. Using the volume of the assay buffer, the amount (in mmol) of oxygen liberated by the photosynthetic tissue can be calculated to give mmol. O_2. min^{-1} that, using the conversion factor 60 s. min^{-1}, can be expressed as mmol. O_2. s^{-1}. The final units of measure to describe the rate of photosynthetic activity are mmol O_2. s^{-1}. mg chl^{-1}; so the amount of chlorophyll in the system needs to be measured and incorporated into the calculations. The chlorophyll in the photosynthetic tissue is extracted into solution and the absorbance readings at the λ_{max} for Chl *a* and Chl *b* of this solution are measured using a spectrophotometer. The amount of total chlorophyll (expressed in mg) is calculated from i) the Chl *a* and Chl *b* absorbance readings ii) the corresponding extinction coefficients of each pigment and, iii) the volume of the chlorophyll extract. In the final step of the calculation the data derived from the oxygen electrode (mmol O_2. s^{-1}) is divided by the data derived from the spectrophotometer (mg Chl) to generate mmol O_2. s^{-1}. mg chl^{-1}. By the end of the experimental process, each student will generate a table that displays the results of the test with the controls so that comparison can be made and interferences drawn. Documenting the number and detail of the calculations involved in this single practical exercise shows that what we are asking our students to do is not trivial. There are many points were students can incur difficulties; students can lose their way when undertaking a multistep process (Trott, 2007) and that applying calculations in life sciences is considered, by some students, to be more difficult than just executing those calculations (Koenig, 2007; Tariq, 2008). Further to this, generating the table of data may be end of the experimental process but it marks the beginning of data interpretation process (Figure 1); the work does not end with the calculations. It is no wonder then that "data analysis" in life sciences has been proposed to be a learning threshold (Taylor, 2006).

The learning strategy that a student needs to adopt to develop their numeracy skills will depend on several factors, two of which are whether they i) lack confidence or ii) the ability to map their numeracy skills into the discipline. Strategies can be designed to engage and challenge the maths anxious biology student (Quinnell and Wong, 2007) and mark a departure from focusing directly on how to 'do' calculations. When a student makes an educationally positive transitions by developing i) their confidence or ii) their numeric skills and/or their confidence (Figure 4), it directly challenges the standpoints of "*I can't do maths*" and "*maths is boring*", which we believe makes the hitherto rigid boundaries around these standpoints dissolve a little and the student's chances of entering their liminal space greater.

Numeric confidence			
	high	a) Student lack numeric skills but do not perceive this to be problematic	b) Student has good numeric skills and are confident in applying them within the discipline
	low	c) Students lack numeric skills and lack confidence	d) Students have numeric skills but lack numeric confidence
		low	**high**
		Numeric skills within the discipline	

Figure 4: Linking students" numeric skill competence with their confidence with these when operating within Life Sciences. Motivating students to shift from low to high with respect to confidence and/or skills requires require our teaching practices to be re-thought.

CONCLUSION

The academic numeracy skills of tertiary students are being explored more fully and have resulted in the creation of networks and resource hubs that focus on learning maths, for example: the Maths, Stats & OR Network at http://www.mathstore.ac.uk/ in the UK; and the Australian Network in Learning Support in Mathematics and Statistics at http://silmaril.math.sci.qut.edu.au/carrick/sites.html. It has become clearer that numerophobia needs to be accepted as an important factor in student learning difficulties at the tertiary level. Our research has added to this work by examining the processes and concepts wherein numeracy skills are important in our students' learning. In outlining our two case studies we have shown advantages of targeting teaching improvements at those key moments where students stumble over numeracy. In the first case study we unpicked the medical statistics topics to identify the key threshold concepts and the concepts that underpin them. Once the overarching threshold concepts were identified, we found it easier to isolate where students uncoupled from the learning process. We discovered that most of these points of uncoupling involved numbers and formulae, and infer that, for numerophobic students, this is a key factor affecting student progress through the liminal space in understanding a threshold concept. Subsequently, successful changes were made to teaching modes and content to enable the numerophobic students to approach both basic and threshold concepts without encountering explanations filled with confusing numbers or formulae. In contrast, the second case study shows a different approach to numerophobia; by challenging students in a diagnostic, students' confidence in their numeracy skills can be improved so that they approach their learning with less anxiety. Both of these methods have proved useful to us and we continue our investigations into how confidence in numeracy affects students learning in practical classes in other life sciences (including genetics and physics). Our future research will focus on threshold concepts and numeracy issues in medical statistics, extending this into the life sciences, as these conceptual intersections appear essential to teaching students how to practise as a statistician or a scientist.

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NOTES

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