

Towards understanding the quantitative literacy demands of a first-year medical curriculum

Vera Frith¹, Geney Gunston²

¹Centre for Higher Education Development, University of Cape Town

²Geney Gunston, Department of Human Biology, University of Cape Town

Correspondence to: Vera Frith (vera.frith@uct.ac.za)

Abstract

Setting. When designing a medical curriculum, assumptions that are made about students' quantitative literacy (QL) competencies often lead to demands that students are unable to meet. In order to improve the match between the literacy demands of the curriculum and the literacy competencies of students, the demands need to be examined critically and the assumptions made explicit. Curriculum changes that reduce the articulation gap between demands and competencies are particularly important for broadening access and promoting success, in tertiary study, for students with disadvantaged educational backgrounds.

Objectives. The objectives of this study are to survey the QL implicitly and explicitly contained in a course curriculum, in a manner that could be useful for the following purposes:

- raising awareness in health science lecturers of the nature and extent of the QL demands of their course materials
- developing the theory relating to best practice for QL development in health sciences
- informing the design of QL interventions.

Method. We focus on the analysis of the QL competencies required of a student engaging with text-based learning materials in the curriculum of a first-year integrated human biology/epidemiology/biochemistry course. For the analysis we use a framework, which classifies quantitative material according to a mathematical and statistical dimension and a competencies dimension.

Results and conclusions. A range of examples is presented which illustrate that the implicit QL demands of this first-year course curriculum are substantial and varied.

Introduction

There has been increasing recognition of the importance of quantitative literacy (QL) in higher education curricula.¹⁻³ QL, also known as numeracy, differs from mathematics in that QL is a practice that is embedded in a specific context, and in which data analysis and interpretation play a prominent role.^{2,4,5} Many academic disciplines, such as those in the health sciences, make complex demands in terms of QL for which traditional mathematics courses do not adequately prepare most students.⁶ For example, although the study of statistics is important for medicine,⁷ it does not usually form part of a student's prior mathematical experience.

In countries like South Africa, where broadened access is a priority and students begin their study of medicine immediately after leaving secondary school, there is a need for curriculum changes that reduce the 'articulation gap'⁸ which exists in many cases between the QL demands of curricula and the students' QL competencies. Curriculum changes that reduce this articulation gap are important for promoting success in tertiary study for students with disadvantaged educational backgrounds.

The literacy demands of many curricula are, however, often implicit. In studying a programme such as medicine, students are expected to be (or become) competent quantitatively literate practitioners within many disciplines. QL can be seen as a set of practices imbedded in the contexts of the various disciplines that students are 'apprenticed' to.⁹ University lecturers, who are competent practitioners in their own disciplines, including its quantitative aspects, may not recognise explicitly the quantitative demands of the discipline or their assumptions about students' QL competencies, both of which can act as barriers to learning.

Definition of QL

QL is the ability to manage situations or solve problems in practice, and involves responding to quantitative (mathematical and statistical) information that may be presented verbally, graphically, in tabular or symbolic form; it requires the activation of a range of enabling knowledge, behaviours and processes and it can be observed when it is expressed in the form of a communication, in written, oral or visual mode.² QL (numeracy), like other literacies, is construed as social practice.¹⁰ However, to engage with situations requiring the practice of QL one must also draw on the practices of the disciplines of mathematics and statistics themselves. The level of the mathematical or statistical knowledge and competence required obviously depends on the context; so for example a quantitatively literate public health specialist would need a high level of competence in statistical reasoning whereas a quantitatively literate histologist would need significant spatial visualisation ability.

In this paper we will present our analysis of the QL competencies demanded by the textual materials in a first-year integrated human biology/epidemiology/biochemistry course at the University of Cape Town (UCT). This course is based on a supported problem-based learning (PBL) curriculum, using paper 'cases' which integrate material from several disciplines, such as medical biochemistry, anatomy, histology, physiology and public health. Supporting activities include lectures, tutorials, practical activities, dedicated-reading resource packs, critical reasoning activities as well as a QL intervention. The QL intervention includes exercises designed to assist all students in acquiring the QL competencies required to solve the problems presented in each of the disciplines in the PBL paper cases. Students who need additional support are identified by testing and receive assistance by means of QL tutorials. Initially, the QL

intervention focussed on the explicit demands of the discipline of public health. However, as students continued to struggle, it became apparent that it was necessary to examine the curriculum to identify the QL demands of all the relevant disciplines.

The supported PBL curriculum of the MB ChB programme at UCT is an example of a secondary academic 'Discourse'¹¹ that the students are expected to master. In fact the MB ChB programme comprises multiple Discourses as it includes several academic disciplines and the PBL pedagogy. Gee¹¹ contends that mastery of a secondary Discourse requires exposure to activities in functional settings and teaching which breaks material down analytically into its component parts, to clarify the practices of the Discourse to students. Northedge¹² describes the role of the teacher as subject expert designing activities that will coach students in mastering the unfamiliar practices of the academic Discourse. This view of the purpose of learning activities underpins the design of the QL exercises and tutorials. We seek to better understand the QL challenges experienced by the students in the secondary Discourse of the MB ChB curriculum, so as to design ways to facilitate mastery of the QL practices of the medical disciplines involved.

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The understanding of textual materials does not require the full range of QL competencies demanded by the curriculum, which also includes more active tasks, such as practical activities, which students complete both individually and collaboratively. The textual materials do however indicate the minimum QL requirements of the course and provide an accessible sample of the quantitative competencies assumed by the curriculum.

Method

The framework used to analyse the QL demands of the curriculum¹³ consists of two dimensions. The first (mathematical and statistical dimension) classifies the mathematical and statistical 'big ideas' that are involved, while the second (quantitative competencies dimension) describes the range of enabling knowledge, behaviours and processes required. The categories within each of these dimensions are elaborated in Tables I and II.¹³

Since the data in this study consist of text-based learning resources, the first three categories in Table II, dealing with the competencies necessary for making meaning from representations, will mostly be used. The last three categories describe competencies that are more likely to be exercised in tasks such as tutorial discussions, practical exercises and written assignments. The framework is however provided for completeness.

In order to develop an understanding of the quantitative demands of the course, all the printed materials made available to students as well as those posted on the Intranet (including PowerPoint slideshows of lectures) were examined. These materials can be loosely categorised under the subject headings: medical biochemistry, human biology and public

Table I. Framework for analysing mathematical and statistical dimension

Quantity, number and operations	For example: <ul style="list-style-type: none"> • Measurement and units of measurement • Different types of number and their representations • Orders of magnitude • Calculation and use of calculators
Relationships	For example: <ul style="list-style-type: none"> • Symbolic and graphical representations of mathematical relationships • Algebra
Change and rate of change	For example: <ul style="list-style-type: none"> • Absolute and relative descriptions of change, e.g. percentage change • Rates expressed as ratios and as gradient of graphs
Shape, dimension and space	For example: <ul style="list-style-type: none"> • Geometry of shapes • Scale factors in diagrams and micrographs • Representations of 3D structures in 2D
Data representation and analysis	For example: <ul style="list-style-type: none"> • Graphical and tabular representations of data • Descriptive and inferential statistics
Chance and uncertainty	For example: <ul style="list-style-type: none"> • Theoretical and experimental probability • Measures of risk

health. Human biology includes anatomy, physiology and histology. Selected illustrative examples of textual materials will be presented. These will be primarily classified according to the mathematical and statistical dimension, but a brief analysis according to the quantitative competencies dimension will also be included for each example presented.

Results

The results of the analysis of the QL competencies required to successfully engage with the text-based learning materials in this first-year course will be presented by discipline.

Medical biochemistry In order to make sense of the biochemistry materials provided, students need to have a good understanding of numbers, ratios, the relationships between variables and the terminology used to describe quantitative ideas, units of measurement, shapes and structures. Extensive demands are made on students' ability to visualise structures in three dimensions and to interpret two-dimensional diagrams representing three-dimensional structures. A well-developed sense of the relative sizes of molecular and cellular structures described or illustrated in the texts is expected. Illustrations may combine structures that vary in size by orders of magnitude. The example in Fig. 1 shows a series of diagrams from the

Table II. Framework for analysing quantitative competencies dimension

Knowing	<ul style="list-style-type: none"> Knowing the meanings of quantitative terms and phrases (verbal representations) Knowing the conventions for the symbolic representation of numbers, measurements, variables and operations Knowing the conventions for the representation of quantitative information in tables, charts, graphs, diagrams and objects (visual representations)
Identifying and distinguishing	<ul style="list-style-type: none"> Identifying connections and distinction between different representations of quantitative concepts Identifying the mathematics to be done and strategies to do it Identifying relevant and irrelevant information in representations
Deriving meaning	<ul style="list-style-type: none"> Understanding a verbal description of a quantitative concept/situation/process Deriving meaning from representations of data in context Deriving meaning from graphical representations of relationships Deriving meaning from diagrammatic representations of spatial entities Translating between different representations
Applying mathematical techniques	<ul style="list-style-type: none"> Using mathematical techniques to solve a problem or clarify understanding - for example: calculating, estimating, measuring, ordering, modelling, applying algebraic techniques etc.
Higher order thinking	<ul style="list-style-type: none"> Synthesising information or ideas from more than one source Logical reasoning Conjecturing Interpreting, reflecting and evaluating
Expressing quantitative concepts	<ul style="list-style-type: none"> Representing quantitative information using appropriate conventions and language Describing quantitative ideas and relationships using appropriate language

prescribed textbook, representing the structure of protein. The following caption accompanies the figure: '(A) The primary structure is composed of a linear sequence of amino acid residues of proteins. (B) The secondary structure indicates the local spatial arrangement of polypeptide backbone yielding an extended α -helical or β -pleated sheet structure as depicted by the ribbon. (C) The tertiary structure illustrates the three-dimensional conformation of a subunit of the protein; while the quaternary structure (D) indicates the assembly of multiple polypeptide chains into an intact, tetrameric protein.'¹⁴

In order to make sense of the representation in Fig. 1, students must recognise and understand that it consists of several different kinds of

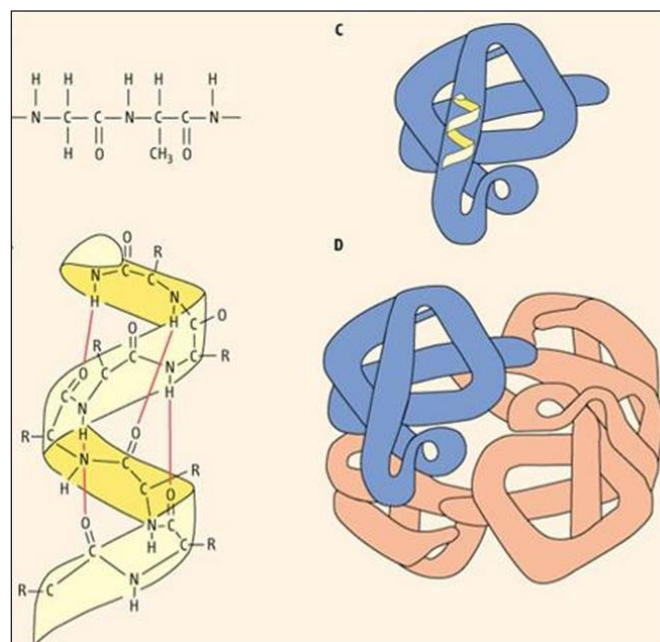


Fig. 1. Example of a two-dimensional representation of idealised three-dimensional structures. PowerPoint slide from a lecture on levels of protein structure. The diagram is reproduced from the biochemistry textbook.¹⁴

representation, ranging from a symbolic depiction of a molecule to a semi-representational picture of the 3D structure of the 'intact tetrameric protein'.¹⁴ They also need to understand the implicit changes in scale between the diagrams as well as the meanings of the quantitative terms used in the text. At the same time, students need to navigate the connections between the text in the caption and the diagrams provided.

The relevant elements required from the 'quantitative competencies' dimension of the framework are:

- knowing the conventions for the representation of quantitative information in ... diagrams ... (visual representations)
- identifying connections and distinction between different representations of quantitative concepts
- understanding a verbal description of a quantitative concept/situation/process
- deriving meaning from diagrammatic representations of spatial entities.

Use of complex graphical representations of the relationships between variables, as shown in Fig. 2,¹⁴ the oxygen uptake curves for haemoglobin and myoglobin, makes significant demands on students' ability to interpret graphical representations and understand the subtleties of thinking about rates of change.

To use the diagram in Fig. 2 to enhance their understanding of the function of haemoglobin, students must appreciate that this is an idealised curve in which each point on the curve theoretically represents a specific state of oxygen partial pressure and consequent oxygen saturation. It is not a curve that can be interpreted by thinking about what happens over time as the blood moves from one part of the body to another (which is the kind of interpretation most students are familiar with for example from introductory physics courses). Most importantly, students must reason about rates of change and understand how the shapes of the curves represent changes in rate of change of oxygen saturation (with respect to

pressure) and to interpret these changes in terms of the physical context. The relevant elements from the 'quantitative competencies' dimension of the framework are:

- knowing the conventions for the representation of quantitative information in ... graphs ... (visual representations)
- deriving meaning from graphical representations of relationships
- interpreting, reflecting and evaluating.

Human biology: anatomy and histology

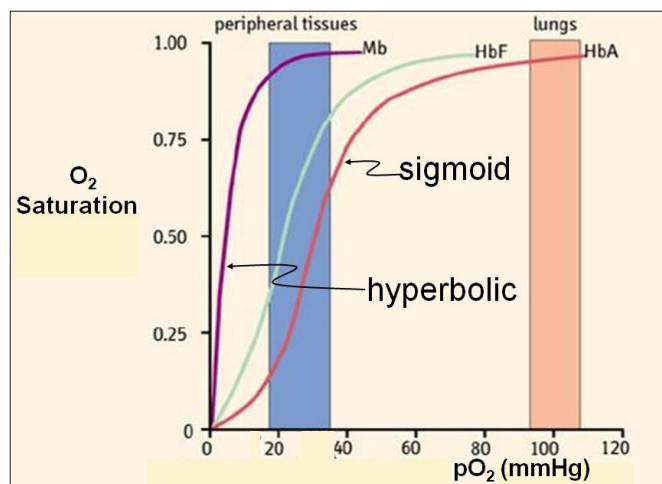


Fig. 2. Example of a graphical representation of a relationship governing a chemical process from a PowerPoint slide from a lecture on protein function. The diagram is reproduced from the biochemistry textbook.¹⁴

To understand anatomical descriptions and diagrams, students must have a sense of the relative sizes of objects described and the ability to interpret representations at a range of different scales of magnification, which are not always explicitly specified. Diagrams provided are two-dimensional representations of three-dimensional parts of the body, requiring an understanding of the point of view (front, back, from below, etc.), the conventions of using cut-away drawings and cross-sections and the mental ability to situate objects within a three-dimensional frame of reference, using the technical language of anatomy.

Human biology: physiology

The material covered in the physiology textbook and in lectures requires the application of numerical insights in the interpretations of a range of (physical and chemical) contexts, for example, the quantification of pressure or the measurement of acidity using a logarithmic scale. Understanding the disciplinary content often requires students to integrate their knowledge of algebra and geometry and to interpret the mathematics in context. Furthermore, the materials place fairly high demands on students in terms of the ability to visualise three-dimensional objects. Some diagrams also include a mixture of realistic representation and 'simplifying' distortions of the actual shapes and relative sizes of physical objects, which must be distinguished by the students in order to interpret them correctly. To understand such descriptions and diagrams, students must have a sense of the relative sizes of objects described and the ability to interpret representations at a range of different scales of magnification. In some cases diagrams are layered inscriptions that have two levels of abstraction within one representation and which require special interpretation skills.¹⁵ An example is where a representation of physical entities

(such as cells or tissues) is combined with symbolic representations of conceptual entities (such as chemical symbols representing reactions taking place). This kind of representation is also common in biochemistry texts.

The physiology materials make use of a very wide variety of diagrammatic and graphical representations, some of which are presentations of information derived from data, such as bar charts, pie charts, and scatter plots (see Fig. 3). In some of these cases the representations are quite complex, requiring fairly high levels of interpretation ability.

For the example in Fig. 3 to contribute to students' understanding, amongst other things they must be able to understand what it means to say that one variable 'predicts' the values of another variable and recognise how this kind of representation can be used to support this kind of statement. They need to appreciate that each plotted point represents a pair of measurements of two variables associated with one individual. They must have a sense of the notion of error in measured data and understand the basis for the concept of a best-fit line and why it is useful. They need also to know what the correlation coefficient is and what one can conclude from its given value ($r = 0.85$). The relevant elements from the 'quantitative competencies' dimension of the framework are:

- knowing the meanings of quantitative terms and phrases (verbal representations)
- knowing the conventions for the symbolic representation of numbers, measurements, variables and operations
- knowing the conventions for the representation of quantitative information in ... charts ... (visual representations)
- deriving meaning from representations of data in context
- interpreting, reflecting and evaluating.

Public health

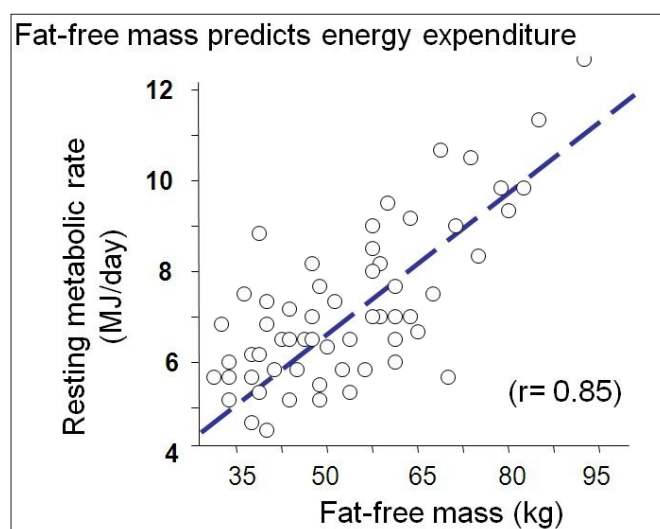


Fig. 3. Example of the results of analysis of data from a PowerPoint slide used in a lecture on obesity and energy balance.

Quantitative concepts and techniques are fundamental to the discipline of epidemiology, and the demands made on students' QL in this component of the course are extensive. The measures used in epidemiology, such as incidence and prevalence and other indices, like birth rates, require

sophisticated proportional reasoning and a fluent use of numerical techniques related to proportions and ratios.

Understanding the concepts in the textbook and other readings also requires critical interpretation of a wide range of data representations and a basic understanding of statistical analysis. A very common way of presenting data is in the form of tables. These apparently simple representations can be very dense and difficult to interpret, particularly if they contain mixtures of absolute quantities and relative measures, such as percentages. To extract useful information from even a simple table, students need to be able to ask questions like 'What comparisons does the structure of the table facilitate?', 'What was used as the denominator in calculating percentages?' and 'What trends is the table intended to display?'

Conclusion

This analysis provides an overview of the QL demands of the textual learning materials for an integrated human biology/epidemiology/biochemistry course in the first year of the MB ChB programme at UCT. The QL demands of the curriculum were found to be extensive and varied.

Examination of the course materials revealed that the ways in which the disciplines are presented in texts assumes a well-developed ability to interpret graphical representations of processes and of data. This is the feature that is probably the most demanding in terms of quantitative reasoning and competence. Anatomy, physiology and histology make extensive use of diagrams to demonstrate structures in three dimensions. A clear understanding of and familiarity with the concepts of scale and magnification is thus essential in these disciplines. Medical biochemistry and physiology, in particular, require the ability to interpret a variety of different complex visual representations.

The degree of algebraic or computational ability required in this course is moderate, but proportional reasoning is fundamental to understanding, especially in the discipline of public health. This discipline also requires reasoning about probabilities and familiarity with data representations and statistical analysis.

The analysis was performed with the aims of raising awareness in health science lecturers of the nature and extent of the QL demands of their course materials and informing the design of QL interventions to reduce the gap between the demands of curricula and students' QL competencies. Although studying mathematics at school must contribute towards a student's QL competency, it is a fallacy to assume that even a successful mathematics student will necessarily be sufficiently quantitatively literate in a context of a programme such as medicine. Other subjects, such as physical science, biology or geography may contribute towards a student's QL, but many students will not have been exposed to data analysis and statistics in anything but a superficial way.

Understanding the QL challenges experienced by students and designing interventions to facilitate mastery of the QL practices of the medical disciplines are important for promoting success in tertiary study, especially for students with disadvantaged educational backgrounds.

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Declaration of interest

We declare that there are no relationships relevant to this paper that could be viewed as presenting a potential conflict of interest.

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