INVESTIGATION INTO DRUG DOSE PRACTICES AND PROPORTIONAL REASONING IN MATHEMATICS AMONG MEDICAL STUDENTS

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PREAMBLE

The research described in this thesis was carried out at the University of KwaZulu-Natal under the supervision of Professor Julia Botha.

Papers and presentations arising from this study are as follows:

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DEDICATION

To my husband,
Stuart,
my parents,
Bill and Pam
And my sons,
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ABSTRACT

Multilingual preclinical South African medical students, receiving a developing quantitative literacy program, were studied. Their preparedness for drug dosage practices, aspects they found difficult, the underlying reasons, and factors or interventio ns that helped them were investigated.

A mixed methods action -research-type study involved three cycles, each testing a different consenting student cohort. In Cycle 1 dosage calculation ability, when using different concentration formats, was assessed progressively over two years. Individual teaching observations explored struggling students' experience. In Cycle II, the focus broadened to include retrieving dosage information from guidelines and preparing a dose in a syringe. In Cycle III, assessment in cluded drug selection, requiring interpretation of statistics to compare treatments. In all cycles, the percentage of successful students was calculated, error frequencies were determined, and associations were sought. Observations were coded for themes of student difficulties, supportive strategies and improvement, responses were mapped to stage progress toward proportional reasoning and assessments were analysed for linguist ic and mathematical difficulty.

In Cycle I (n = 364), competence rose from 23% to 66% after extended exposure to training and assessment, peer learning and individual tuition. Observed tuition themes produced curriculum change. In Cycle II, 239 students were randomised to four groups. The two groups given standard numerical information fared best (46% success with the addition of equipment and 43% without). Where information was extracted from guidelines, 25% were successful when provided with equipment and only 10% without. Groups with equipment calculated fewer implausible doses and u sed fewer incorrect units. In Cycle III, after training, only 26% of 231 students understood relative risk, but a mere 6% understood the concepts of absolute risk and number needed to treat. Sixty students (26%) made a rational drug choice. Proportional re asoning ability was not associated with interpreting risk statistics successfully or making a rational treatment selection. In all cycles, English as home language predicted success, although in Cycle I, this effect was lost after peer tuition.

To prepare medical students for the complexities of drug dose practices, early training and repeated assessment should include extraction of information from guidelines, use of the relevant equipment as well as training in interpreting risk statistics for rational drug selection.

ABBREVIATIONS

APS	academic performance score
ARR	absolute risk reduction
CI	confidence interval
NNT	number needed to treat
PBL	problem-based learning
RR	relative risk
RRR	relative risk reduction
SAMF	South African Medicines Formulary
STG	Standard Treatment Guidelines
UKZN	University of KwaZulu-Natal
ZPD	Zone of Proximal Development

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CHAPTER 1 INTRODUCTION

1.1 Background

The numerate individual uses quantitative skills to understand the varied settings of the world (Orrill, 2001, p. xviii), including the workplace. A definitive case statement has been developed, listing behaviours, and their underpinning skills, involving this kind of thinking, which is also called quantitative or mathematical literacy (Steen, 2001). Those relevant to clinicians treating patients include rational drug selection, helping patients understand different treatment option risks, and administering drugs in an appropriate amount and rate. Rational prescribing depends on an understanding of different ways of representing risk: ratio concepts which include risk ratios, absolute and relative risk, and the 'number of patients needed to treat', abbreviated as NNT (Therapeutics Letter Working Group, 1996). Communicating treatment option risks to patients involves an understanding of how these different risk representations may influence the patient's choice of treatment and an ability to represent risk in different ways to assist a patient in making sense of the numbers. Dosage calculations of drugs in solution require an understanding of an intensive quantity- concentration, which relates the mass of a drug in solution to the volume of the solution. The drug concentration may be represented in either a mass/volume format, as a ratio or as a percentage. Choosing an appropriate rate at which drugs to be administered by infusion are given is dependent on another intensive quantity- flow rate. These behaviours and their underlying skills that clinicians rely on when treating a patient all require proportional reasoning. Because medical students must achieve high scores in school mathematics to be selected from many applicants for a hard-fought place at medical school, and school mathematics has been assumed to prepare students for the quantitative literacy-based skills they would need at medical school and in the workplace, the abilities of medical students, has until recently largely been assumed.

The ability to select a drug and its dose and to format a prescription according to legal requirements are skills required to perform competent prescription writing, a competency which is required for practice in the pre-registration year. It has been recommended that this skill is taught and assessed before graduation. (Burch et al., 2005). When these skills were introduced as part of the pharmacology and therapeutics programme at the medical school, this study arose from a desire to ensure that our students are equipped with the necessary quantitative literacy and other skills related to drug dosage practices that are needed so that they will be prepared for the demands of these workplace tasks.

1.2 Context

This research has focused on students studying medicine in their preclinical years (Years 1-3) and their fourth year over the last ten years at the Nelson R Mandela School of Medicine, University of KwaZulu-Natal (UKZN), South Africa. The medical school has been producing doctors since 1950, when it was founded in the apartheid years as a "black faculty" in a "white institution". For most of its history, the School has been synonymous with the struggle for democracy and racial equality (UKZN, 2017).

Students come from a range of socioeconomic backgrounds and high schools, including government funded public schools and the usually more expensive, privately funded schools. Of the total intake of medical students at UKZN, a minimum of 15% of places are reserved for students from schools serving communities with a socioeconomic status within the lowest 40% of the population (UKZN Applications and Information Office, 2019).

Within quotas, school leaving examination success is used to select students. Minimum requirements include a performance level of 60% for Mathematics, Physical Science, Life Sciences and English. English, the language of instruction, must have been studied at school and be a home or first additional language. Many students have one of the ten official South African languages other than English as a home language, and some would not have had English as their language of instruction at high school for subjects other than English.

These students are learning within the context of a newly democratic post-conflict society. (Vithal, 2012). This period also follows several other transitions: curriculum changes in mathematics education in South African schools, a shift to problem-based learning (PBL) in medical education at UKZN and a call for movement toward competency-based teaching in medical education internationally. The MBChB programme involves a mix of lectures, problem-based learning, clinical bedside teaching, research electives and rural attachments. After three preclinical years, students begin intensive clinical training. Candidates are exposed to clinical situations from the first year onwards, with increasing time spent on wards and in clinics where they are given increasing responsibility as their medical training progresses. (UKZN College of Health Sciences, 2019). Teaching is disease-based, with diseases introduced in PBL cases grouped together in themes related to different body systems, for example, the cardiovascular theme, the respiratory theme, or the gastrointestinal theme. Lectures supporting the learning occurring during the PBL sessions are included in the themes (Van Wyk & Madiba, 2006). Drug management of these diseases is taught by pharmacology and therapeutics subject specialists and clinical specialists as they arise in the themes. Students are assessed in end of theme tests and end of semester examinations. During the course of this research, the PBL curriculum at UKZN was adapted to accommodate a foundation course in the first year, with PBL beginning in the second year (Tufts & Higgins-Opitz, 2012). The foundation course included a module, Basic and Foundational Skills, comprised of material necessary to underpin the learning that would occur during the PBL programme.

1.3 Significance

Patients missing out on the best choice of drug for their disease and those receiving the wrong dose of a drug can suffer significant iatrogenic morbidity and mortality. Irrational prescribing is associated with suboptimal treatment and unnecessary health risks and costs (De Vries et al., 1994). Dosage error, a significant finding in a report by the National Patient Safety Agency in the UK, remains an important

source of morbidity and mortality worldwide (Lewis et al., 2009; Simpson et al., 2009; National Patient Safety Agency, 2009). Doctors have been found to make different treatment decisions depending on the format of the treatment risk statistic used to communicate information about the efficacy of a medicine, resulting in irrational treatment decisions (Covey, 2007). Clinicians in Australia are less competent at dosing than they believe they should be (Simpson et al., 2009). Difficulty with ratio concepts accounts for most suboptimal mathematical proficiency and predicts poorer health outcomes in the USA (Reyna & Brainerd, 2007). Such difficulties also cause medical students in the UK to struggle with dosage calculations when the concentration is written as a ratio or percentage (Wheeler et al., 2004).

Drug dosage has been alluded to as a problem among South African medical students (Harries et al., 2006), but the extent and nature of the problem is not known. It is also not known how South African medical students interpret treatment risk information. This requires comparing the risk of a negative outcome when being treated with different treatment options, and reasoning about how a treatment changes risk, relative to no treatment. These skills require complex proportional reasoning. This has been found to be a 'threshold concept', explained by Lloyd and Frith (2013; 2016) as a 'gateway to ways of new learning', for numeracy and critical thinking that very few students have reached. This research is the first to investigate drug dosing practice skills, dependant on proportional reasoning and essential for safe and effective treatment of patients, among South African medical students.

1.4 Review of the literature

Proportional reasoning, the ability to make comparisons between objects using multiplicative rather than additive thinking is complex. Lamon (2007) proposes that proportional reasoning requires mastery of different areas of understanding which include partitioning, unitising, quantities and change, rate, rational numbers and relative thinking. She reviewed proportional reasoning and rational number research and found that all proportional reasoning could be described as involving one of two problem types: 'comparison problems' and 'missing value' problems. In the first, two ratios a/b and c/d must be compared to see whether a/b is larger or smaller than c/d or whether the two ratios are equal. For the 'missing value' problems, students would be given two equal ratios a/b and c/d and three values e.g. *a, b* and *c* and they would calculate the fourth *d.*

Proportional reasoning, a key arithmetic skill (Steen, 2001), underlies the numerical skills of drug therapy. An understanding of intensive quantities, such as concentration or the rate of flow of an infusion fluid, which are important for drug dosing practices, rely on proportional reasoning. These comprise two extensive quantities (e.g. mass and volume or volume and time) that are combined to form a special ratio (e.g. concentration or flow rate) and that do not behave additively unlike extensive quantities, such as mass, volume and heat (Dole. et al., 2009). Proportional reasoning is conceived as a 'threshold concept' (Lloyd & Frith, 2013), a term developed by Meyer and Land (2003) to describe

certain key concepts which act as a gateway to full understanding, which, when mastered, open a door to new ways of thinking. Such concepts are transformative, irreversible, integrative and involve 'troublesome knowledge', which conflicts with older forms of understanding, which must be discarded or changed in order to accommodate the new thinking. As students struggle with this process and with accepting the new counterintuitive thinking, they must proceed through an uncomfortable transitional state (called the liminal space). Prior to this stage, students are in a preliminal stage of understanding. Students within the liminal space may use the new learning in a way that involves rote learning or copying without really understanding the reasons behind the actions. Such behavior can be seen in the experiences of Frith and Lloyd (2016), who describe learners relying on a memorised formula to work out certain relative risk problems and reaching for a calculator before first assessing whether the numbers are easy enough to work out mentally. This has been experienced in the setting of the research for this thesis also. Learners can stay stuck in this state or emerge with a transformed understanding.

Because medical students have achieved in school mathematics, a requirement (UKZN website) to be offered a place at medical school, and because mathematics learnt at school has been thought to transfer to the mathematics encountered outside school (Stasz, 2001), students have been expected to have proportional reasoning skills that can readily be transferred to the clinical setting. However, school mathematics success does not necessarily guarantee workplace numeracy. Research suggests that mathematical knowledge transfer does not happen readily (Stasz, 2001). Steen (2001) explains that mathematics becomes increasingly abstract. The disconnect between written assessment and workplace skills goes further, as revealed in recent ethnological studies of mathematics in the workplace, where for example, nurses who may be unable to perform drug dosage calculations on paper may dose accurately in the ward, using different reasoning strategies to do so (Hoyles et al., 2001; Stasz, 2001).

The sociocultural approach of Vygotsky takes cognisance of the context in which learning occurs, that it involves special tools or artefacts and a specific way of doing things. Memories are coded enmeshed with this situational information and consequently the presence of artefacts and the way in which a task is processed affects the ability of the learner to retrieve the learning. This occurs to such an extent that the workplace artefacts become represented as mental tools in the mind of the worker. Novices develop competence through guided participation in an authentic task. The context of the work is not static but constantly changing and being shaped by the learning that occurs in the context, so the work of the novice and guide can change this context as it leads to the creation of new tools, processes, relationships and environmental conditions (Vygotsky, 1978a). The learning occurs when novices are able to work within their Zone of Proximal Development (ZPD). This is at a level between the skills they have mastered and those which they can perform with the assistance of a guide (Vygotsky, 1978b). It is the guide's responsibility to provide sufficient support and challenge to keep the task within this zone.

With the sociocultural recognition of the importance of engaging with authentic tools and tasks (while still maintaining the task within the ZPD), it would be expected that students would acquire proportional reasoning skills transferable to the workplace when these are learned during exposure to the authentic components of a task. Consequently, it would assist learning and transfer of skills to the workplace to include as many authentic components of a task as can be achieved within the limits of ethical considerations and the constraints of the classroom. The extent to which authentic contextual factors relevant to the workplace are included in teaching, learning and assessment would be expected to affect its relevance to workplace numeracy. However, inclusion of such contextual factors in an assessment was also expected to change students' ability to demonstrate competence. Stasz (2001) explains that sometimes when the goal is to learn mathematics, some workplace contexts may require so much focus on contextual factors that students' focus is shifted from the mathematics to the detriment of their learning. She says that while situated learning is valuable, the importing of workplace examples into the classroom is 'fraught with conceptual and practical problems'. We were interested in seeing what contextual aspects made problems more difficult and what helped students demonstrate competence.

Although Vygotsky's guide is in a position of greater power, (compared with a novice), he assumes the guide has the learner's best interests of the learner at heart. Through being responsive, the guide ensures the learner's voice is not ignored. However, detrimental learning can also occur when a faulty guide abuses the position of trust and power, leading to processing and products that are not mutually beneficial. Critical theory seeks to generate emancipatory forms of knowledge to provide alternative and progressive ways of looking at the world. Frankenstein (1983) argues that the mathematically literate individual should be one who is empowered to go beyond functional literacy to ask why the numbers have been formatted in a particular way, how the chosen format serves the producers of the figures, and how the numbers would be interpreted if they were formatted in a different way. Clinicians must use this kind of thinking to assess numerical risk information in order to guide a patient in making the most appropriate treatment choice, bearing in mind that this is not the primary goal of the producers of the figures. Students have been found to experience difficulties with proportional ratio concepts, which impeded the development of their ability to reason critically about quantitative information (Lloyd & Frith, 2013). The level of difficulty of proportional reasoning was found to be dependant on the task context in which it was being used. While the Lloyd and Frith study was undertaken among law and humanities students, it is not known what impact the proportional reasoning skills of medical students have in the context of tasks involving critical reasoning. During dosage calculations, students are required to reason proportionately about numbers, e.g. an amount of drug (a quantity) in a volume of solution (a quantity). In the more difficult context of comparing health risk statistics, students must reason proportionally about percentages (e.g. a change in risk (%) compared with the initial risk (%)) as well as reasoning critically about why figures have been presented in the way that they have, and what form of presentation will best serve (and emancipate) the patient. They must also not be fooled by

taking the numbers at face value without considering the baseline level of risk (Natter & Berry, 2005). This is a task that trips up clinicians (Akl et al., 2011) and even health authorities (Fahey et al., 1995), who have been found to interpret the same risk differently, and to be motivated to use a medicine to a different extent, depending on the type of statistic used to describe the efficacy of the treatment. This makes reasoning proportionately in the second context more difficult. An aim of this study was to determine how this increased difficulty impacted on students' ability to show their proportional reasoning skills by performing the task of interpreting different treatment risk information competently.

Medical students have been found to struggle with both calculating doses and interpreting treatment risk statistics (Wheeler et al., 2004; Chao et al., 2003). Sheridan and Pignone (2001) assessed the numeracy of 62 medical students: the 46% who responded to a survey which involved answering three questions, one relating to probability, the second requiring the working out of a percentage (1% of 1000) and the third converting '1 in 1000' to 0.1%. They found that 23% of students could not answer all three questions correctly and that the students also had more difficulty interpreting treatment risk statistics.

While South African students' abilities were not known, there was reason to believe that their skills would not be adequate for the competencies they require during preregistration. Firstly, a South African study conducted at the end of the medical school years (involving medical students who had graduated, but not yet registered) showed a lack of preparedness strongly suggestive of inadequate skills underpinning drug dosage practices. Competencies required for practice in the pre-registration year were tested, and prescription writing was found to be the worst performed skill (Burch et al., 2005). Secondly, looking at Cape Town students at the start of their medical school education, Frith (2011), in her motivation for a quantitative literacy course now offered by her institution, describes the results of assessment questions, which suggests that they did not have the quantitative literacy skills that faculty assumed they had. These were skills that would be required to cope with the demands of the medical school course. Students found the course useful and it improved their formal assessment performance. The course focussed on the quantitative reasoning underlying public health information and diagnostic skills rather than those involved in prescribing and dosing drugs. Finally, a subsequent study looked at South African students hoping to access higher education, comparing their quantitative literacy success in the entrance examination required by many universities, the National Benchmark Test, with school subjects. They found that most students lacked sufficient proficiency to cope with the quantitative literacy demands of higher education without additional support, and that scores in matric subjects Mathematics and Mathematical Literacy did not predict proficiency (Prince &Frith, 2017).

Proportional reasoning is a key skill underpinning quantitative reasoning, and both rational prescribing and administering the appropriate amount of drug are clinician competencies depending on this kind of reasoning (Steen, 2001). However, in South Africa, medical students' ability in relation to these

proportional reasoning-based skills, such as calculation of drug doses and interpretation of treatment risk statistics has received little attention. There is also no local information looking at how these skills relate to their underlying quantitative literacy and proportional reasoning skills.

1.5 Problem Statement

Effective and safe drug treatment of patients requires that doctors are able to select appropriate treatment and then calculate and prepare the correct dose of the chosen medicine. Rational treatment selection depends on the use of linguistic skills and on proportional reasoning to correctly interpret information comparing treatment risks, as does the ability to calculate doses. Until recently, medical students' proportional reasoning ability and literacy was assumed. It was thus expected that they would have no problem with these tasks, once given a brief introduction to new contextual information, such as information about the different risk statistics and the different ways of expressing concentration in drug dosage calculations. This was because high school leaving examination scores in mathematics are a prerequisite for a place in medical school. In the same way, because of high scores in school English examinations (either at home language or first additional language level), it was assumed that students would have the necessary linguistic skills to perform these tasks.

However, worldwide, doctors and medical students have been found to struggle with interpreting treatment risk information, making rational treatment choices and calculating drug doses. For multilingual medical students, little is known about the numeric and literacy skills needed to make a rational treatment selection and prepare appropriate drug doses even though these are essential practices if clinicians are to provide safe and effective drug treatment.

1.6 Aim

To evaluate medical students' numerical and linguistic skills, in relation to drug dosing, at various stages of their training and in response to different interventions.

1.7 Research Questions

1. How successful are medical students in dosage calculations at the start of training?
2. What interventions improve medical students' success?
3. How does broadening a drug dosage practice task to include more workplace contextual information change success?
4. What proportional reasoning skills do students demonstrate during drug dosage practices of increasing difficulty?
5. What linguistic skills and challenges do students demonstrate during drug dosage practices?
6. What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?

1.8 Conceptual framework

This study takes the perspective of Lipkus and Peters (2009), regarding numerical processing for decision making. They are of the view that when making a decision, information is processed using two different modes of thinking: a deliberative mode and an affective/intuitive mode, with one system affecting the other, and that good decisions are made when these systems work together so that a decision involves both thinking and feeling. They have developed a theoretical framework of numeracy in decision making that describes these processes that people use to form conclusions. This framework can be used to make sense of 'health numeracy', the ability to use numerical information to guide health decisions. It also explains why health communicators need to pay attention to this processing in order that people understand information in the way it was intended. Lipkus and Peters (2009) believe that dual process theory explains how numerical information is understood and acted upon. This theory deals with two different systems: System 1 is intuitive, based on gut feel and emotions and is fast and automatic. System 2 is slow, deliberate, and rational, and is based on reason and analysis. The two systems do not work independently; each system informs the other.

They consider manipulating numbers such as converting frequencies to percentages and vice versa, to be a System 2 operation. Highly numerate people pay more attention to numbers and are more likely to display this number agility. Numeracy also affects how the affective meaning of numbers is interpreted (the 'felt goodness or badness of the comparisons' that influences whether a person will accept information to guide decision making). Highly numerate people feel more motivated by the numbers to make a decision, while less numerate people seem to be more influenced by non-numeric information (e.g. anecdotal health information shared by a role model). System I, or gist processing is involved during qualitative comparison of proportions i.e. focusing on the bottom-line meaning of information (e.g. whether one risk is importantly higher than another), rather than calculating an exact number. (Lipkus & Peters, 2009).

The numerosity or ratio bias effect, causes preference of options with smaller probabilities but larger numerators (Nelson, 2008). This has been found to mislead people thought to be using gist thinking (System I processing) uncritically. Highly numerate people are thought to use System 1 to pay attention to a number, then to use System 2 to compare proportions (both numerator and denominator). The numbers then motivate them to decide, while less numerate individuals might ignore the denominator, or be distracted by formatting differences when making decisions involving numbers (Lipkus & Peters, 2009).

In this study, learning is viewed from the sociocultural perspective of Vygotsky, where understanding occurs first as a social interaction between a learner and a guide (a more skilled individual) while working together performing a meaningful task and subsequently in the individual as an internal

dialogue (John-Steiner & Mahn, 1996). According to this view, a teacher would ideally provide just sufficient scaffolding (such as collaborative dialogue) to ensure that students remain within their ZPD, Vygotsky observed students trying to satisfy task requirements that were just beyond their reach, as this offered insight into the normally hidden processes underlying the beginnings of new skills. This focus assisted him in determining strategies that could be offered to assist struggling students to move to the outer limit of their ZPD. For Vygotsky, performance level was most useful for providing information about what sort of task should be the next focus of the guide and learner's joint attention (John-Steiner & Mahn, 1996). Threshold concepts theory fits well with this approach as, in the Vygotsky view, learning is a qualitative transformation that occurs during social or internal dialogues. Vygotsky's scientific enquiry involved a dialectic approach, which views phenomena as syntheses of contradictions. The dialectic approach fits well with the imagery of moving through the liminal space of a threshold concept to emerge with a transformed understanding.

For Vygotsky, learning and the context in which it occurs shape each other. The methodology of action research, where interventions are implemented as part of practice, observed and assessed, and reflected upon to shape new practice and so drive development, fits well within this paradigm. Action research is used to foster development by doing research during a practice, and then using the findings to adjust future action. Action research tends to occur in a series of cycles as adjustments are made, assessed and considered before a new adjustment is made (Cassell & Johnson, 2006). Using the language of the sociocultural perspective and threshold concept theory, and different research methods, all fitting within a series of action research cycles, this study aims to explore how best to guide students, within their ZPD through the liminal space and across the threshold to proportional reasoning competence. It aims to look at this competence in the context of different skills, which it underpins, skills that are essential for the practice of prescribing and dosing drugs. In evaluating the development of student competence in these drug dosing skills, other essential skills and factors, such as linguistic ability and contextual knowledge, must also be considered.

CHAPTER 2 METHODOLOGY

2.1 Methodological approach

The sociocultural perspective of Vygotsky recognizes the importance of the voices of both learner and guide engaged in collaborative learning. Its focus on learning through dialogues means that the interaction between the learner and more competent guide should be an essential area of focus. Sociocultural researchers emphasise methods which focus on the interaction between participants focusing on a meaningful activity and which document cognitive and social change. They are interested in the voices and perspectives of the teacher and the learner and the level of responsivity between them. (John-Steiner & Mahn, 1996). Early on in this research, the learner and teacher are observed as the learner struggles to work through a calculation that had been too difficult to work through alone, and the teacher has to diagnose the problem and provide just the right support to keep the student engaged with the work. Noting where the student stumbles and what the nature is of the support that is offered, provides rich information that directs the type of interventions and lines of enquiry that follow.

In the Vygotskyan perspective, special attention is paid to partial learning, to what a learner can do with assistance, as this indicates what potential a learner has and what independent skills will follow. It is a predictor of future competences. Consequently, this study employed a range of data collection methods that look at partial learning as well as demonstrated competences. These aspects of the study afforded the chance to go beyond studying what Vygotsky calls the 'fruits of learning' (a successful calculation, a correctly prepared dose or selection of the most effective drug). They also reveal Vygotsky's buds or flowers of learning', a student's ability to achieve competence during the guided learning process which predicts a students' potential ability (Vygotsky,1978b). A student whose qualitative comparisons of two graphical representations of treatment event reveals reasoning that is within the liminal zone, which precedes crossing the threshold to reasoning proportionately, might also be considered to be showing a 'bud or flower of learning'. Analysis was therefore aimed not only at determining which students had succeeded in showing evidence of proportional reasoning. It also provided an opportunity to stage students whose reasoning was not fully developed. Similarly, students who got three types of dosage calculations correct out of the four assessed, and had previously only got one question correct, showed evidence of learning, although the learning was not yet sufficient to succeed at all the dosage calculations that could be encountered in practice.

Vygotsky recognized the importance of language in learning: the dialogues with a more competent guide is the language that will become internalized for learners, and the language of the workplace tasks must be learnt in order to be able to perform the skills required competently. For Vygotsky, a workplace skill cannot be understood separate from the workplace tools, the understanding of which forms part of the memory that is coded and makes it easier to recall the skill, The context is inseparable from the learning which in turn produces artefacts that shape and change the context. To understand the learning involved in drug dosage practices, Vygotsky's perspective makes sense. Many of these dosage skills

rely on proportional reasoning, but they also involve specialized language and contextual information that must be made sense of before proportional reasoning and quantitative literacy skills can be demonstrated. Looking at drug dosage tasks through the eyes of learners navigating this learning in a language that is often not their own home language, lays bare the complex tacit learning involved in these skills.

According to the Vygotsky perspective of learning being embedded in practice, it makes sense to learn through practice, by observing practice, by analyzing the results of classroom interventions and assessments and using these to drive curriculum change and further enquiry. Consequently, a line of enquiry was followed along the lines of action research, where practice drives enquiry and theory (Womack, 1997). A new element was added to the curriculum and a group of students were followed and assessed. Following careful observation and discussion with students chosen to represent the range of variability, curriculum changes were made and new lines of enquiry were followed with the intention that the classroom tasks would prepare students for the workplace skills as close as possible to how they would be encountered. Because real classes were receiving tuition, the students moved away into their clinical years in hospitals before they could receive the benefit of the changes they had helped shape, but the dialogues they had been part of changed the learning context for the cohorts of students that followed. Two of these cohorts were then studied and assessed, each receiving a different intervention aimed at preparing them to dose drugs competently in the workplace. A second aim of these interventions was to understand the nature of the relationship between contextual factors, linguistic skills and proportional reasoning that formed part of the quantitative literacy skills required to develop competence in these practices. The research involving the original cohort of students and then the two cohorts that followed the initial curriculum change are considered to form three action research cycles, Cycles I to III. The three cohorts of students will be referred to as Cohorts 1 to 3.

Cassell and Johnson (2006) report that the range of action research is so diverse that there seems to be no unifying theory. They say this is because they have developed from different philosophical stances about how knowledge is generated. They divide the action research types that have developed from these stances into five main groups: experimental action research practices, inductive action research practices and three types of participatory-type action research. Each of these approaches produce different tensions for their practitioners. The experimental researcher must balance competing demands of working in a natural setting while aiming to eliminate bias to show cause and effect. The inductive researcher must try to capture an authentic account of the participants' version of reality. Researcher tensions for participatory approaches, involve ensuring participants all have a voice and that unequal power relations don't cause distortion of any consensus reached.

This study is along the lines of action research in that practice drove enquiry, and some of the findings led to a change in practice ,after which further observation and assessment were conducted. The study design involved elements of mainly experimental and participatory action research practices and the accompanying tensions. For many aspects of the study, participants were a convenience sample of those in class on a particular day. When Cohort I could no longer be sampled, because they no longer attended medical school, a new Cohort was observed and assessed. These pragmatic decisions affected the internal validity but it was still possible to draw some useful conclusions. On the other hand, the observation of the one on one interaction of student and teacher during a dosage calculation task prompted behaviours in both the student and the researcher that the researcher aimed to describe. There was a power differential because the researcher chose the activity and judged the correctness of the process, while the student was more vulnerable, being observed doing an activity that was difficult. However, the interaction did give the student the opportunity to speak directly and privately to the teachers. No students were able to choose the topic of the learning and the assessment; the teacher exerted this control over the students. However, students could choose not to participate in learning interactions, which were not compulsory. Also, the teaching material was chosen because it fosters academic literacy and numeracy skills that would assist them in other medical school learning activities, while developing a workplace competence e. So, in keeping with a sociocultural approach, the (future) workplace drove the direction of the learning.

Rather than seeing a dichotomy between quantitative and qualitative research, in sociocultural research, approaches are chosen that emphasise process and development, and the multiple ways in which both can be revealed (John-Steiner & Mahn, 1996). In order to allow students a voice and to explore the direction the curriculum should take, a range of qualitative data collection methods were required. It was necessary to observe teacher-student interactions, and to analyze assessment responses to diagnose barriers to student thinking and to look at how far along the path to proportional thinking students could show they had come. It was necessary to analyze written assessment questions, in terms of both linguistic and proportional reasoning and other mathematical procedural difficulty, to understand the complexity of the tasks students faced. Interviews afforded students an opportunity to diagnose what they perceived within the tuition and assessment to be barriers to learning. A study conducted in cycles is considered appropriate for an emerging mixed methods study, where new research questions arise during different stages of the research project. (Bryman, 2006). A mixed methods study design was expected to provide greater insight than either type by itself. Quantitative results would inform the selection of study participants for some of the qualitative work, while qualitative results would elaborate and provide clarity to the quantitative results, as well as generate data that would suggest new lines of enquiry.

For the qualitative research, the data was analysed using thematic analysis, which is an interpretive method that involves recognising patterns that emerge when the data is studied. Interesting pieces of information e.g. text is labelled with a 'code', which is like a soundbite of meaning that stands for the labelled piece of information. As the work develops, these 'codes' may be combined or renamed. Codes that fit together are then grouped together to form themes. The codes and themes that develop will be informed by the research question and the methodological approach of the study. Thematic analysis works from the premise that the parts and the whole must be made sense of in relation to each other, so the researcher, while interpreting the information, moves between the full text and the code, and between the data of one sample and the others, to see whether a code developed in one sample might also label information in another. It is a method that can capture interpreted information as well as descriptive information. The approach of interpretive methods is that reality is formed from people's subjective experiences or interpretations. In this view there is no objective knowledge that is not first thought about. For this reason, knowledge is formed by examining the phenomenon of interest in a semi-structured way. Interpretive methods are often inductive, so the researcher tries to approach the data with an open mind and make sense of the data they encounter, and uses the interpretations made to build a theory. This contrasts with the deductive method involved in quantitative methods, where a researcher begins with theory that is used to form a hypothesis which will be rejected or not depending on statistical tests. In this type of research, the qualitative equivalent of validity, trustworthiness' is strengthened when a detailed description of procedures is provided, so that readers can understand how the researcher made the decisions they did. (Roberts, Dowell & Nie, 2019).

At the same time, with large student numbers in each class and the researchers coming from the positivist tradition of pharmacology, some objective evidence of the benefit of different interventions was sought. An incorrect dosage calculation in the workplace could mean a negative consequence for a real patient, so ideally students should leave medical school with evidence that they are equipped with this key competence and can calculate the doses of drugs they will encounter. Likewise, prescribing a drug that is not optimal for patient treatment could mean poorer health outcomes for a patient. Quantifying students' ability would allow students' progress to be tracked within the same cohort. Competence at the different skills could be compared to determine where to focus intervention efforts, and to determine the contribution of linguistic and, contextual skills, and proportional and other quantitative reasoning complexity to the level of success students were able to demonstrate. Quantitative measures of success also allowed the progress of the quantitative literacy curriculum to be gauged, by comparing different cohorts of students (to the extent that non-randomised groups of students with demographic and other differences can be compared).

Cohen, Manion and Morrison (2011) explain that the perspectives of both normative and interpretive approaches are necessary and inseparable aspects of understanding human behaviour and experience and this view is echoed by other authors. (Neuman, 2000; Entwistle & Ramsden, 1983). Cohen and colleagues (2011) also recommend using mixed quantitative and interpretive methods to look at a phenomenon from different perspectives and to benefit from the strengths of the different methods. With this in mind, mixed methods were used to answer each of the research questions.

2.2. Overall study design

The research was conducted in sequential cycles (Clark & Creswell, 2011) each with a different cohort of students. In the two years following Cycle I, two first year classes were studied, comprising the cohorts for Cycles II and III respectively. The results of the first cycle informed the research questions asked in Cycles II and III. Also, the results found in Cycles I and II informed curricular changes and changes in competencies expected of the students in subsequent cycles. Each cohort is followed for a different length of time. While the cohorts in Cycles I and III are followed longitudinally for over a year, cohort II is only tracked to the extent that there is information about the training students have been offered, before they participate in a randomised controlled trial which provides a one day focused snapshot of student ability.

Research questions 1,2 and 6 involve the development of the quantitative literacy curriculum, while research questions 3,4, and 5 focus on aspects thought to influence drug dosage task difficulty (the role of artefacts, proportional reasoning skills and linguistic skills). The first two research questions, namely

> '1. How successful are medical students in dosage calculations at the start of training?' and
>
> '2. What interventions improve medical students' success?'

were answered by assessments conducted in Cycle I among the first cohort of students. The final research question

> '6. What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?',

involved the third cohort of students (in Cycle III), whose results for the skills that had been taught and assessed in previous cycles were compared with those for previous cohorts.

For the remaining three research questions focusing on the different ways a drug dosage task varied in difficulty, the involvement of different cycles and cohorts was as follows: the third research question

> '3. How does broadening a drug dosage practice task to include more workplace contextual information change success?'

was answered by the results of a randomised trial of the second cohort of students in Cycle II. The design of the different assessments testing ability to interpret treatment risk and to make a rational

treatment choice conducted in Cycle III (among the third cohort of students), when compared with earlier tasks, and students' success at these tasks, was aimed at resolving the fourth research question

> '4. What proportional reasoning skills do students demonstrate during drug dosage practices of increasing difficulty?'.

In order to answer the fifth research question

> '5. What linguistic skills and challenges do students demonstrate during drug dosage practices?',

students in the randomised trial conducted in Cycle II were compared. Those who received the more difficult linguistic task of making sense of excerpts from treatment guidelines to retrieve numeric information were compared with those who had only to make sense of the language of the paper problem to retrieve numerical information. Results from the three cycles were reviewed to determine the influence of having a home language other than the language of instruction. Assessment material from the three cycles was analysed to compare the readability of the different questions encountered.

2.3. Participants

At the start of the study, class sizes at medical school were a maximum of 200 students. By the time Cycle II began, class sizes had increased to around 250 students. The cohorts of students comprised convenience samples (students who happened to be part of a class in a particular year). Consequently, the sample sizes between each cohort differed because the research progressed from one group of students to the next as the first cohort of students moved on from medical school to the clinical years. The first cohort of students in Cycle 1 were two classes of Third Year students (2009 and 2010). There were 164 from the first class, 180 from the second and 20 who repeated, and participated in both the first and the second class. The two classes of students received the same tuition and types of assessment questions, and were subject to the same rules for being exempt from certain formal assessments or requiring a supplementary examination. The two classes were pooled to decrease any effect that might have resulted from being a member of one particular class and to increase the sample size. Students who had to repeat the fourth year were excluded from the study. For each class, student demographics and results were not significantly different The pooled sample is considered to be one cohort, and referred to as Cohort 1. The second and third cohorts were two consecutive first year classes (2012 and 2013). For the assessments within each of the cycles, in most cases, students were a convenience sample of the students who were present at the lecture session where the assessment was administered or those required to participate in the formal assessment being conducted. Consequently, the number of students varied. For the observed individual tuition, two samples of students were selected as described in Section 2.6.2.3.1.

2.4 Ethics

The study was approved by the University's Biomedical Research Ethics Committee (reference number BE185/09). After written information was provided, and repeated verbally, each participant gave written informed consent to the publication of the overall findings from their data.

2.5 Curricular training in quantitative literacy for drug dosage practices

As the research is embedded in the quantitative literacy (QL) programme that was offered to students it is necessary to describe this in detail and how it changed as the curriculum developed. This section described what tuition was offered and what assessments were given to each of the three cohorts within each research cycle. However, first it is necessary to clarify what was meant by the construct 'curriculum', and what philosophical perspective has been taken. According to McKenna (2003) "curriculum" is perceived in different ways depending on the philosophical viewpoint of the teacher. Curriculum changes are made according to this perspective. In the current study, curriculum is viewed from the Vygotskyan perspective. This is in line with McKenna's description of an interpretive view of curriculum as being shaped by the teacher and student, the classroom and a wider context (e.g. the needs and demands of the workplace). Strategies benefiting students during the one-on-one teaching observation were included in future large group teaching, for example. However, in keeping with the mixed methods approach, the perspective of curriculum varies to fit the different aspects, and to serve different purposes. The curriculum was viewed from a positivist perspective when student success was deemed quantifiable and the effects of curriculum changes e.g. the teaching interventions were measured. Later, in Cycle III, a critical emancipatory perspective led to the inclusion of treatment risk interpretation to make rational treatment decisions as a skill in the quantitative literacy curriculum. The goal here was to teach students to think critically about why different risk statistics are chosen in different types of written material, and how different formats can mislead. Like Matthews & Van Wyk, (2018) we have been guided by the view of the Health Professions Council of South Africa (HPCSA) that the medical school has a responsibility to adapt the curriculum to meet the needs of the communities it serves in order to be socially accountable. The decision to included dosage calculation and interpretation of treatment risk statistics to make a rational drug selection in the curriculum was to ensure patient safety.

2.5.1. Cycle I

Students in their third year at medical school received an hour of tuition, where they were introduced to relevant contextual information they were unlikely to have come across, such as how administration sets worked and what a drop factor was. Then, using the 'scalar two column stepwise method' (for details see Paper 2), they were taught to calculate volumes when the concentration was expressed as a mass per unit volume, a ratio or percentage and how to work out drip rates. They were guided through worked examples, which involved drugs and recommended doses from South African guidelines. They

were then given calculations to work through as homework, which were discussed in a feedback session. A set of step-by-step model answers was also provided electronically. The tuition was included as part of a large group session during regular teaching (as part of the pharmacology lectures). As these sessions were not compulsory, the rate of attendance is unknown.

Dosage calculations were included during all the formal assessment of the theme, providing opportunities for students to review the material and demonstrate competence (details of this are described in the Study Design section of this Chapter, as well as in Paper 1). An hour-long revision session preceded the assessments, and feedback was provided in assessment report back sessions, where calculations were worked through.

After analysis of results students were selected for individual tuition (discussed in the next section, Study Design), where those who took up the opportunity worked through the questions they got wrong, with guidance provided when required.

Students were provided a further opportunity for dosage calculation tuition during the fourth year when they had been split into two groups (surgery and medicine), and spent most of their time in hospitals. Each group was offered an hour of tuition during a session of lectures they had at medical school before the groups switched between surgery and medicine. This hour comprised a tutorial where students were able to work through dosage calculation questions in small groups, allowing for discussion in their home languages. The tutorial and model answer were made available electronically after the session. Dosage calculations were formally assessed in the fourth year. Examples of the dosage calculations involved in tuition and assessments are included in the Appendices.

2.5.2. Cycle II

A subsequent group of students in their first year at medical school were trained and assessed (the reasons for shifting dosage calculation tuition to the first year of study is explained in the next section, 'Design and data collection methods'). This involved typical dosage calculations and teaching material as described in Cycle I (the lecture, assignments, feedback and model answer). Teaching was adapted to address some of the conceptual barriers observed during Cycle I, such as difficulties with intensive quantities (see Chapter 4 and Paper 2) and some revision of relevant mathematical literacy topics such as unit conversions and conversion between common fractions and decimal fractions (see Chapter 4).

In addition, in response to feedback from our research in Cycle I, teaching was extended to include navigation of treatment guidelines to retrieve dosage information. Guided examples and feedback was provided as in Cycle I. Three assignments for self- assessment were provided, involving typical dosage calculations where numeric information was provided, as well as those requiring retrieval of dosage

information from guidelines. Students received ten hours of tuition, six hours involving typical dosage calculation and four involving retrieval of information from guidelines.

After this tuition, students were randomised into groups and assessed as described in the next section, 'Study Design,' and in Paper 3.

2.5.3. Cycle III

A third group of students was assessed as they received quantitative literacy training focused on drug dosage practices. At the start of their first year, these students' proportional reasoning ability was assessed (as described in Paper 4). Students received tuition as described in Cycle II. Both typical dosage calculations and those requiring extraction of numerical information from guidelines were included in formal assessments.

Students also received 3 hours of tuition involving interpreting treatment risk statistics (used to compare drug efficacy) and using them to make a rational treatment decision as described in Paper 4. The tuition involved formative assessment. Students were first required to imagine they had a risk factor for a disease and to decide whether they would take a treatment based on a statement providing treatment risk information. They were asked to repeat this exercise twice, each time with a statement that described treatment risk using a different statistic. This question is included in the Appendices.

In a different exercise, students were asked to look at a graphical representation of two treatment rates, one for a treatment group and one for a group receiving placebo, and to describe the size of the treatment graph relative to the placebo graph. (This question is included in the next section, 'Study design".). Students submitted their responses for marking and received feedback in a classroom lecture. There it was revealed that for the first exercise, the different risk statistics, though they involved different quantities, actually described the same risk and that the same treatment was being described. If students made a different decision about whether they would take the medicine when its efficacy was described using a different risk statistic, then they had not made a rational choice. This was aimed at surprising students so that they would experience how easy it is to be fooled by treatment risk statistics. For the graphical comparison, students were shown how this information could be used to calculate three different risk statistics, the kind used in the treatment choice exercise. The statements involving treatment risk statistics, the graphical treatment rate comparisons and the results table are typical of the way treatment efficacy is reported in medical journals and advertisements.

Ability to interpret treatment risk statistics and use of these statistics to make a rational treatment decision was reviewed in a lecture involving statistics in the cardiovascular module in the first term of the second year, and then formally assessed in the theme test.

2.6. Design and data collection methods of the aspects of the study

Tables 2.1 and 2.2 gives timelines of the different student tuition and assessments conducted in each cycle, as they relate to the QL programme, the preclinical years at medical school and the year they took place. Details of the student cohorts that comprise the participants for the different cycles and the samples drawn from these for each assessment is also provided. Each assessment is cross-referenced to the detailed description of the assessment that follows in this section, as it fits within one of six parts of the study, each designed to answer one of the study questions. For each research question, the design of the study components aimed at answering it is explained, first with a diagram describing how the qualitative and quantitative aspects or strands fit together, then with an explanation of the study design of the separate components which includes details of the competences required for students to be deemed successful. Examples of the assessment material are either included in the methodology of the aspect or in the Appendices.

Table 2.1 Cycle I timelines of issues and their actions: tuition, assessment and curricular change

Timeline		Issues and Actions tuition, assessment and curriculum change	Location (Section in thesis, supporting paper or reference)
from start of QL programme	**within medical school curriculum**		
Timeline Prior to study in earlier student cohort		**Issue 1:** When students in the clinical years requested prescribing training, dosage calculation was the worst performed skill.	Botha et al. 2006
Study begins			
Cycle I Cohort 1 (*n* = 364)			
0 months	3rd Year 1st Semester (2009 & 2010)	**Action 1a**: dosage calculation tuition	Section 2.5.1
2 months	End of Theme test	**Action 1b**: Assessment	Section 2.6.1.2. Paper 1 Page 72 Paper 2 Page 80
At 2 months		**Issue 2:** most did not show full competence	
0-12 months	3rd Year End of theme tests, End of module (semester) exam, end of year exam & supp exams	**Action 2**: assessed (variable number of times) and at 12 months (cumulative)	Section 2.6.2.2. Paper 1 Page 72 Paper 2 Page 80
By the end of 12 months		**Issue 3** a. most failed to show full competence cumulatively b. error analysis: researcher could not follow reasoning for many students c. many implausible volumes	
12 months	After the supplementary examinations during the end of year holidays	**Action 3a:** 10 of the least successful students & 13 unsuccessful students (stratified sample) given observed individual tuition	Section 2.5.1 Section 2.6.2.3.1 Paper 2 Page 80
12 months		**Issue 4a:** Observed tuition revealed conceptual and procedural mathematical difficulties, linguistic issues & need for more contextual information	
13-24 months	Clinical group returned to medical school for a faculty lecture morning (each group offered one session) (2010 &2011)	**Action 3b:** 364 students offered group learning session (each offered one session)	Section 2.5.1 Section 2.6.2.4.
18 months	One group who were offered a session as above (2011)	**Part of action 3b:** 200 students offered a particular group tuition session with peer learning opportunity attendees (*n* 83) & non attendees (*n* 117)	Section 2.6.2.4 Paper 2 Page 80
24 months	4th year end of clinical block exams (2011)	**Action 3c: calculated** cumulative number deemed competent in one or more tests	Section 2.6.2.2.1. Paper 1 Page 72 Paper 2 Page 80
By the end of 24 months		**Issues 4b** i).Two thirds of students showed full competence ii). Students receiving individual tuition improved iii). Group tuition caused improvement	
Action 4 Curriculum Change Included tuition to remediate difficulties observed during individual teaching (Issue 4a) Shifted to the first year within the medical school curriculum			Section 2.6 Curriculum changes
Issue 5: Uncritical acceptance of implausible volumes (see Issue 3b)			
Issue 6: Reviewers questioned the validity of written dosage calculation assessment			Hoyles et al., 2001
Issue 7: Article involving proportional reasoning gaps hindering student critical thinking about numbers in South African law students led to consideration of tasks involved in therapeutics requiring proportional reasoning and opportunites for transformative learning			Lloyd & Frith, 2013
Action 5 Cycle II Second cohort of students (*n* = 239) Dosage equipment to provide natural limits (issue 5) & workplace task alignment (issue 6 together with guidelines) **Action 6 Cycle III Third cohort of students (n = 256)** a. Assess benefits of additional dosage calculation tuition material (see Action 4) b. Add tuition: guided naviagation of guidelines to retrieve numerical information (see Action 5) c. Add learning interventions designed to build critical thinking about numbers while developing a competence required for rational prescribing: interpreting drug treamtnent risk statistics (aimed at addressing issue 5 and 7			

Table 2.2 Timelines of student tuition and assessment Cycles II and III

Cycle 2 Second cohort of students (*n* = 239			
Timeline from start of QL Programme	**Timeline within Medical school curriculum**	**Tuition and Assessment Received**	**Location (Section in thesis/ Page in Paper)**
0-3 months	Year 1 Term 2	dosage calculation tuition including retrieval of numerical information from guidelines	Section 2.5.2.
3 months	Start of Term 3	Randomised to 4 groups Group 1: given numerical dosage information and calculated a dose Group 2: extracted dosage information from guidelines and calculated a dose Group 3: as for Group 1 but also prepared dose using formulation and syringe Group 4: as for Group 2 but also prepared dose using formulation and syringe	Section 2.6.3.3. Paper 3 Page 96
Cycle III Third cohort of students (*n* = 256)			
Timeline from start of QL Programme	**Timeline within Medical school curriculum**	**Tuition and Assessment Received**	**Location (Section in thesis/ Page in Paper)**
0 months	First Year First Term (2013)	proportional reasoning skills assessment (*n* 247)	Section 2.6.4.3. Paper 4 Page 124
0-6 months		new dosage calculation tuition	Sections 2.5.2. & 3
9 months	First Year Term 4	sample (*n* 157) asked to make treatment decision based on treatment statistics	Section 2.6.4.4 Paper 4 Page 125
9 months	First Year Term)	qualitative evaluation of two treatment risks presented as a graph (*n* 175)	Section 2.6.4.5.
12 months	First Year End of Year Examination\	dosage calculation assessment typical questions (*n* 127) and extracting dosage information from guidelines (*n* 127)	Section 2.6.4.6
9months and 15 months	First Year Term 4 Second Tear Semester 1 (Theme 2) (2014)	training in interpreting treatment risk statistics	Section 2.5.3 .
18 months	Second Year End of Module (Semester) Exam	assessment of ability to use treatment risk statistics in the form of a results chart: one question on relative risk (*n* 139) and one question on absolute risk (*n* 97) assessment of ability to make a rational drug choice (*n* 16)	Section 2.6.4.7. Paper 4 Page 125 126

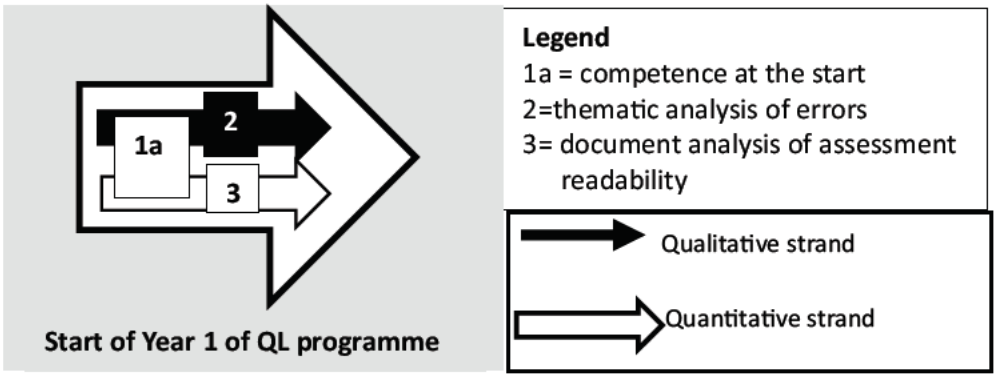
Cycle I

2.6.1. Research Question 1

How successful are medical students in dosage calculations at the start of training?

2.6.1.1. Mixed methods approach

Figure 2.1 Strands comprising aspects answering Research Question 1



This comprised a quantitative cross-sectional study (assessing dosage calculation success in the students' formal assessment) with a qualitative strand and a quantitative strand embedded within the cross-sectional study: first a thematic analysis of student responses focused on the types of errors they made and second, a readability analysis of the calculation questions.

2.6.1.2. Quantitative aspect: cross-sectional study of student dosage calculation competence

2.6.1.2.1 Design and procedures

Medical students in their third year, were introduced to different types of dosage calculations. After tuition (details in Section 2.2), they were formally assessed during the students' end of theme test. One of the problems involved calculating an infusion drip rate. The three remaining questions involved determining the required volume of a formulation of a drug in solution, or the amount of drug contained in a formulation. The relationships were given as a concentration, either expressed as 1) a mass divided by a volume 2) a percentage solution or 3) a ratio /rate. The proportion of questions correct was calculated for each student and the proportion of students scoring 0%, 25%,50%,75% and 100% was calculated.

2.6.1.2.2 Measures of success

To be deemed competent, students needed to answer all of four dosage calculation questions correctly, with each question measuring a different type of calculation. The rationale for this measure of competence was that if students can show they can calculate the different calculation types then they show a broad range of skill, and competency at the proportional reasoning and understanding of the contextual information they would need to successfully calculate similar doses or drip rates. This would

also allow the ability shown to be compared with their ability at other stages (without having to give students the identical questions in a subsequent test) or with the success of other students asked similar questions. The different question types are described in 2.6.1.2.1. Success at the 75% level (as opposed to 'full' or 100% competence) required answering three of the four questions correctly, and allowed partial success to be identified.

A second measure of success was also calculated, as calculations could be considered to be potential 'patients'. The number of mistakes students made as a group was then divided by the total number of calculations students tried. This was to determine the percentage of potential 'patients' that would have received the wrong dose had the students actually been calculating and administering doses to real patients (and conversely, the number of correct calculations as a percentage of total opportunities would give the percentage of' 'patients' receiving correct treatment).

Finally, for each question type, the percentage of student success was calculated and the success was compared for the different questions to compare their difficulty.

2.6.1.2.3 Methods of analysis

Demographic factors of students who were deemed competent were compared with those of students who did not demonstrate dosage competence to determine whether any demographic factor was a predictor of dosage competence. Those tested were gender, having English as a home language, and school success.

Epi-Info 7.2.2.6. (Centre for Disease Control, 2011) was used to assess whether there was any association between these demographic factors and success, with the chi-square test being used for categorical data (gender and having English as a home language) and ANOVA to compare the numerical data of the mean school leaving score of successful and unsuccessful students. A p-value of less than 0.05 was considered to be statistically significant. Relative risks and their 95% confidence intervals (95%CI) were also calculated.

2.6.1.3. Quantitative aspect: readability analysis of questions

The readability of the questions were measured according to Flesch Reading Ease Score, a measure of the comprehensibility of text. It is calculated using the following algorithm: Flesch Reading Ease Score = 206.835 – 1.015 x (Total Words / Total Sentences) – 84.6 x (Total Syllables / Total Words). The score ranges from 0 to 100, with scores of 0 to 30 equating to the reading of the average college graduate. Text scoring higher scores is considered to be more comprehensible, with a score of 90-100 corresponding to the reading level of a Grade 5 student. An online calculator was used to work out the

Flesch reading Ease Scores (Flesch Kincaid calculator, 2019). The scores and reading levels were compared to determine whether differences in comprehensibility between calculation types might have contributed to the difference in success between calculation types.

2.6.1.4. Qualitative aspect: thematic error analysis of student responses

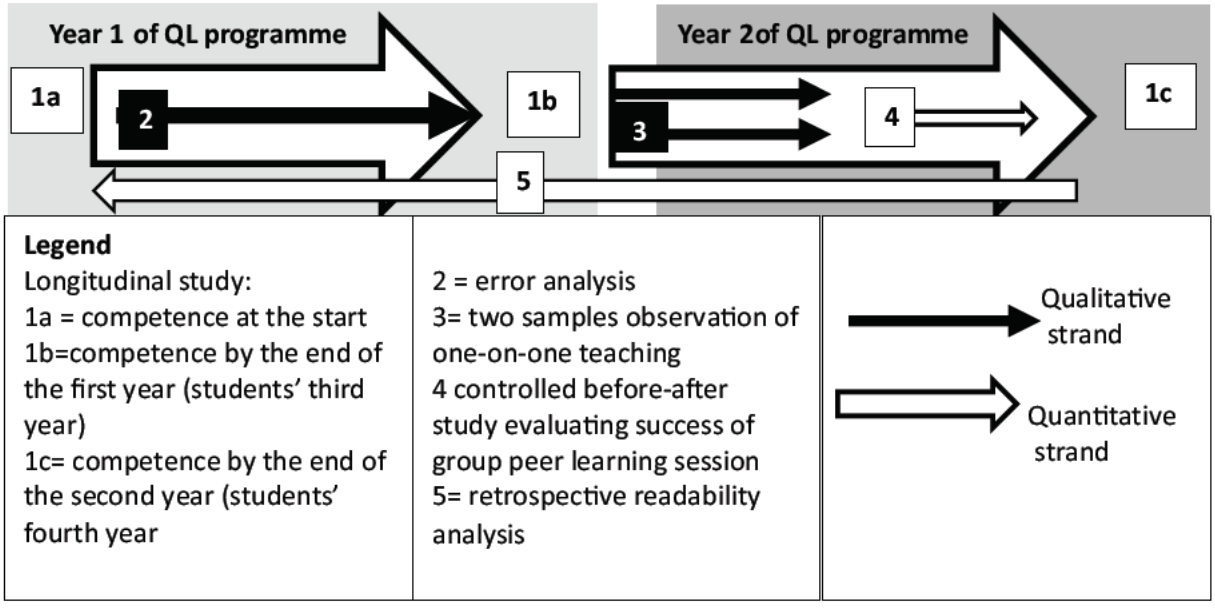
Responses were analysed by categorising the evidence of different types of errors. This was combined with the data gathered in subsequent tests, which is discussed in the next section in the work conducted to answer Research Question 2. The researcher began by having a quick look through all the responses as the correct responses were separated from the incorrect ones. This allowed the researcher to develop a few codes which were related to reasons for errors e.g. 'wrong units' or 'decimal error'. Then each response was given one or more comments which described the diagnosis the researcher had made of where the student's processing had gone wrong to cause the incorrect response. As a new code developed, the previously coded data was reread to check that this code did not apply to it, and if necessary, a code was added. Where the reasoning could not be followed, the researcher would label such a response 'no idea'. This was continued until each student answer sheet had at least one of these diagnostic comments. The set of responses was given to a second researcher who also made a comment, although the second researcher had the list of codes available that the researcher had used and used these codes where applicable, rather than developing their own. The two comments or codes were compared and discussed until a consensus was reached about which codes fit best. The frequency of the codes was determined for the data set to determine the most common reasons for incorrect results.

2.6.2. Research Question 2

What interventions improve medical students' success?

2.6.2.1 Mixed methods approach

Figure 2.2 Strands comprising aspects answering Research Question 2



This comprised a quantitative longitudinal study tracking attainment of competence over two years. The study began with the first assessment after tuition in the first year of the intervention (during the third year of the medical curriculum and already described in 2.4.1 Research Question 1). The percentage of students who could demonstrate dosage competence at that stage was calculated. It continued to assess the competence attained by the end of that year (the cumulative percentage of students who had demonstrated competence by this stage) and then went on to assess the competence reached by the end of the second year of the intervention (the fourth year of the medical curriculum). Embedded within this study was a qualitative strand (an error analysis) spanning the first year of the intervention. This was followed, before the start of the second year of the intervention, by two qualitative strands (two samples observed during one-on-one teaching) at the start of the students' fourth year of study, followed by a quantitative strand (testing the success of a group peer learning session), all embedded within the quantitative study that tracked competence. Finally, a quantitative readability analysis of the assessments used during Cycle 3was performed.

Quantitative results at the end of the first year of the intervention, (at point 1a in Figure 2.2), together with the results of the error analysis (indicated by the arrow marked 2 in Figure 2.2) informed the selection of a group of participants for one-on-one interaction (indicated by the arrow marked 3 in Figure 2.2). Quantitative results at the end of the first year of the intervention informed the selection of a second group of students showing the very poorest proportional reasoning abilities (also indicated by the arrow marked 3 in Figure 2.2). Analysis of these one-on-one teaching interactions led to a further intervention- group tuition with opportunities for peer teaching and learning (indicated by the arrow marked 4 in Figure 2.2). Finally, all the assessment questions were assessed to determine and compare their readability (according to the methods described in 2.4.1.3 and indicated by the arrow marked 5 in Figure 2.2.). All the quantitative data was used to provide a longitudinal view of cumulative demonstration of ability for each student.

2.6.2.2 Quantitative aspect: longitudinal study

2.6.2.2.1 Design and procedures

In this longitudinal study, students received tuition and then were given - and took up - a varying set of dosage calculation learning opportunities. Their progress was followed into their fourth year during repeated formal assessments to see how their exposures affected their outcomes. The study was considered to be longitudinal, rather than a series of case studies in which all individuals received the same intervention or had the same outcome.

The students that were assessed in 2.4.1 in order to answer the first research question were followed over two years, during which they received various types of dosage calculation training. They were tested intermittently until the end of fourth year by the inclusion of a set of four dosage calculations in

formal exams and tests. The inclusion of these questions in formal assessments over the course of two years provided students with opportunities to display competence (see Section 2.4.2.2). Like the initial assessment described in the previous chapter, the four questions were comprised of different question types, one involving the drip rate, and the remaining three determining the volume of a medicine that needed to be administered when the drug concentration was expressed either as a mass per unit volume, a ratio or as a percentage. . For each student, the percentage score achieved was recorded as well as which calculation types were answered correctly. The percentage of students who achieved competence cumulatively by the end of the third year and by the end of the fourth year was measured. Because some students failed and wrote supplementary exams, and some who excelled in the end of theme test received exemption from writing the end of module examination, some of the students were tested more often than others. The average number of tests it took to reach competence was calculated.

Recognising that competence once achieved might not be retained or might be achieved over more or less assessments, the percentage of time a student was successful was also calculated as well as the proportion of potential 'patients' that would have been harmed due to being treated incorrectly. This latter quantity was determined by calculating the number of mistakes made by the students as a group relative to the number of calculation opportunities. The number of errors that were made in total were determined altogether, for the group that showed competence initially (Group 1), for the group developing competence during the study (Group 2) and for the group who failed to attain competence (Group 3). For the groups attaining competence, the students' ability to demonstrate retention of competence was measured: the number of errors made after competence was reached, as well as the percentage of time that students were competent was determined.

In order to compare the difficulty of calculation types, the percentage of time a particular type of calculation was answered incorrectly was also determined. This work is described in Paper 1.

Tracking students longitudinally also offered the opportunity to determine associations between some of the different teaching interventions provided and subsequent outcomes (details of this are described in Section 2.4.2.4 and in Paper 2).

2.6.2.2.2 Measures of success

As for the initial assessment (Section 2.6.1.2.2), a student was deemed competent after getting all four calculation types correct (scoring 100%) in a particular test, while success at the 75% level required answering three of the four questions correctly. This allowed competence to be compared at different stages of tuition. Competence was measured cumulatively. Also, as for Section 2.6.1.2.2, the number of mistakes students made as a group was then divided by the total number of calculations students tried as a group, to determine the percentage of potential 'patients' that would have received the wrong dose

had the students actually been calculating and administering doses to real patients. (Conversely, the number of correct calculations as a percentage of total opportunities would give the percentage of' patients' receiving correct treatment.)

2.6.2.2.3 Methods of analysis

Relationships between certain demographic factors and the development of competence by the end were tested using Epi-Info 7.2.2.6. (Centre for Disease Control, 2011) to determine whether these predicted success. The demographic factors tested were gender, having English as a home language, and school success, measured by students' matric score. The chi-square test was used to test for associations for categorical data (gender and having English as a home language), while ANOVA, used to compare numerical data, assessed the mean school leaving score of successful and unsuccessful students. A p-value of less than 0.05 was deemed to be statistically significant. Relative risks and their 95% confidence intervals (95%CI) were also calculated.

2.6.5.2.3 Qualitative aspect: error analysis & Observed tuition

2.6.2.3.1 Design and procedures & participant selection

At the end of the first year that students were tracked, students' success was ranked by dividing the total number of dosage calculations answered correctly by the number of calculations included in the formal assessments they wrote. The written calculation responses of students who had made errors were analysed and codes were developed to categorise the different types of error encountered. Incorrect responses for each question were categorized as: 1) omitted, 2) 'no idea' (meaning the researchers could not follow the student's information processing) 3) used incorrect units 4) decimal error 5) formula error 6) arithmetic error 7) correct answer in wrong format.

The written calculations did not allow students to confirm or deny their reasoning, and many students failed to write down their calculation steps or left out questions. Consequently, it was decided to conduct an observation of selected students as they worked through some of these one-on-one teaching interactions as this was expected to reveal the different ways that students might reason, that might prevent successful dosage calculation. For the observed teaching sessions, two samples were selected, guided by the quantitative assessment and error analysis.

First, in order to focus on the causes of the unfathomable errors and to capture all the variability of reasoning within the cohort of students that led to unfathomable answers , a sample of students who had the most questions categorised as omitted or 'no idea' was selected. This was stratified across the range of ability of students not demonstrating competence (determined by the ranked dosage calculation success scores for the year). A second sample focused on the poorest performing students. This comprised all of the students who scored zero in at least one of the assessments after the initial

assessment for that first year of the study, and who did not reach competence by the end of that year. The two groups of students were invited to attend an observed individual tuition session and interview. All those who attended, after giving their written informed consent, were asked to try a worksheet which was comprised of each of the questions the student had not answered correctly in previous assessments. Students who did not respond to the invitation were followed up by email and telephonically in an attempt to encourage as many students as possible to set up an individual tuition session. Students were asked to record their calculation steps on the worksheet and work out the problem aloud (along the lines of the 'think aloud method used by Denig et al. (2002) to expose students' decision processes and give insight into their conceptions of prescribing). While the student worked through calculations previously done incorrectly, sometimes explaining their reasoning aloud, dialogue and actions were observed. Where students did voice their thoughts, this allowed their thought processes related to calculating doses to be transcribed and examined. If a student got stuck, the researcher provided just sufficient information or explanation to enable the student to continue and would make a note of the difficulty experienced by the student. This provided an opportunity for the strategies which helped students to progress after they had faltered to be revealed. The researcher also noted student behaviours and their perceptions of the emotions students' body language communicated relating to their sense of competence. Students were asked about their experience of the teaching and assessment of dosage calculations as well as their suggestions related to how their learning could be improved. Their responses were also recorded in writing In addition, all interviews were recorded. The process involved two teacher-researchers, one who was engaged in the one-on-one tuition, the other who observed and took notes and occasionally joined in with a strategy or suggestion to assist the student. The teacher involved in the one-on-one tuition also made case notes after the session.

For pragmatic reasons, successful students were not invited for one-on-one tuition as it would take up their time without the opportunity for remediating dosing skills as these were already evident. The one-on-one observations provided the opportunity to compare the characteristics of the more able students in the stratified group with those of the struggling students, to reveal attributes associated with success. Successful students were also specifically not selected for observation because this was not expected to offer insight into developmental stages or the way in which students learn so that they progress toward competence. According to the threshold concepts theory, once learned, a threshold concept cannot be unlearned (Meyer & Land, 2003), so observation of successful students would provide no information about the process of crossing the threshold, and reflecting back on this crossing to articulate details about the steps in this process is difficult (Meyer & Land, 2003). According to sociocultural theory, successful students can accomplish the task independently so would no longer be working in the ZPD.

2.6.2.3.2 Methods of analysis

An exploratory thematic analysis was conducted to find key themes both for the error analysis and the observed teaching session. For the error analysis, categories were developed and the proportion of errors for each category was determined. The process for developing categories was the same as was described in 2.6.1.4, with the researcher beginning by using the codes developed in 2.6.1.4 and adding additional codes or categories if necessary.

For the observed individual tuition, the two researcher teachers involved had a brief discussion after the session regarding the notes they had made. Where anything differed they reached a consensus about their interpretation of student reasoning and the behaviour displayed. As the researchers were new to this method, the notes were not later corroborated with the student involved, and by the time the researcher became aware of this technique to strengthen trustworthiness, the students were not able to be contacted and had left medical school for their clinical years. This is a limitation of the study.

Case notes were analysed by one researcher using QSR NVivo 8 (2008). Student question response sheets and recordings were used in addition to develop codes, which were used to form key themes. First the researcher typed the handwritten case notes, reflecting on what had been written. Then the typed case notes and question response sheet belonging to a particular student was read carefully and the recorded session listened to. The case notes were then coded through QSR NVivo 8 (2008). This was repeated for each student. If a new code was used for a student, the researcher went back through the notes of the other students' notes to determine whether they should receive this code or if a code should be changed. This process was repeated until all the student interviews had been coded and no new codes were being developed. As the observed teaching was ongoing, the students that had been selected for interview and had not made appointments were followed up. When no codes were being developed from data, the researcher stopped making follow-up calls for defaulting students, although any invited students who contacted the researcher received teaching and were included in the data. (Any students from Cohort I were welcome to attend such a session and one student did request this- this was a student who had achieved competence, so her teaching session was not included in the study).

As the data was approached without a set of predesigned categories to be sought for as codes, codes and themes were considered to develop in an inductive process. However, the researchers did have a specific focus for their notetaking. An explicit focus was that they were looking for information that helped them understand the students' reasoning process when solving a drug dosage calculation. They asked students about their experience of the teaching interactions and assessments and whether they thought these had contributed to their failure to demonstrate competence. At the same time, they were looking at the interaction between teacher and student through the sociocultural lens. Although this focus was implicit, the consequence of this was that they looked for signs of the teacher acting as guide

and of the student being guided. They looked for signs of a student struggling and what accommodations were made to help the student succeed. The codes and subsequent themes that developed reflect both types of focus.

2.6.2.4 Quantitative aspect: assessment of success of teaching interventions

In response to the observations made during the error analysis of third year formal assessments and individual tuition of selected students that followed the third year assessments, tuition was continued into the fourth year. Consequently, students improved, as has been discussed previously. The success of some of the teaching interventions employed over the course of student tuition was then assessed. Because student competence was assessed as the years progressed, the benefit of time and practice on competence could be evaluated. In addition, the impact of efforts to improve the interaction between students and experts could also be evaluated. These experts were the teachers providing the individual tuition for selected pupils and the more competent peers who fostered peer-assisted learning during a fourth year tutorial (details in Section 2.2.1).

Student competence by the end of the third year at medical school (their first year of dosage tuition) was compared with competence by the end of the fourth year of their medical studies (the second year of tuition). In order to determine the impact of time and practice on competence, the proportion of students who became newly competent in their third year were compared with those developing competence in their fourth year.

One of the teaching interventions in the fourth year involved a tutorial where small groups of peers solved dosage calculations together, allowing an opportunity for discussion between peers with the same home language. This was conducted in one of a set of lecture sessions students received from faculty at medical school when students, split into groups, returned from their clinical training in hospitals before switching between types of training. These sessions were offered to groups of students at different times depending on their clinical schedule, but all students were scheduled for one such set of lectures. For one such session, a record was kept of the students who had been scheduled for the lecture session who attended. As the students scheduled for the lecture were assessed before and after the tutorial, these assessments could be analysed to determine the benefits of this type of tuition, with the non-attendees of the group acting as the control group. The details of this are described in Paper 2.

The success of individual tuition, besides being measured qualitatively (see Section 4.3.3.for the development of one of the key themes: ‘Experience of developing competence’), was also measured by following the competence demonstrated in assessments by the students who received individual tuition. Their progress as they progressed from the start of tuition to the end of the third year and then to the end of the fourth year was tracked.

2.6.2.5 Quantitative aspect: readability analysis

The average readability of the different questions used to test each question type was calculated and compared. The paper problems used to test each question type were analysed for readability using the Flesch-Kincaid scale

Cycle I competencies required

By the time they completed their preclinical years, students were expected to show competence so that they would be prepared for the work they would encounter in the clinical setting. It was expected that they would be able to answer each of four calculation types correctly in one formal assessment by the end of the third year. This was considered to be 100% competence. A lower level of competence (a 'partial competence' as a measure of progress towards full (100%) competence) was also measured, this being the number of students who got three of the four calculation types right in a single formal assessment, considered to be competence at the 75% level. After succeeding, they were expected to retain this competence in subsequent assessments. When this level of success was not reached or retained by all students by the end of the students' third year, teaching and assessment was extended into the fourth year in the hope of improving the percentage of students who had demonstrated competence.

Curricular changes informed by findings in Cycle I

Reflection on the findings produced in Cycle I led to changes in the content taught and the shifting of the tuition earlier to the start of the preclinical years. Cycles II and III followed these teaching changes.

Following Cycle I, dosage tuition was shifted from the third and fourth years to begin from the first year. This occurred partly in response to the findings described in Chapter 4 and discussed in Paper 2, that students' competence improved with repeated assessment opportunities during their third and fourth years. As students in their fourth year are based at hospitals and only rarely return to medical school, and then only do so split into groups who return on two separate occasions, it made sense to shift the teaching and assessment to earlier in the curriculum so that ideally students would begin their clinical years having developed the necessary competence. Introducing dosage calculation at the start of their time at medical school would allow students time for repeated learning and assessment. In addition, it would allow time to extend competence to fit more closely with the workplace mathematics involved in drug dosage practices. It was also hoped that it would build student quantitative literacy that could assist them to remediate weak areas revealed during the observed learning and equip them for the quantitative literacy demands of other medical school modules. Frith (2011), describing a quantitative literacy course for medical students at UCT, lists the quantitative literacy requirements within different medical subjects. She notes 'Proportional reasoning is fundamental to understanding in many situations,

especially in the discipline of public health. This discipline also requires reasoning about probabilities and the ability to interpret and critique data representations and statistical analysis.' Due to a change in curriculum to incorporate a year-long foundation course, which includes a Basic and Foundational Skills module, dosage calculation skills tuition and other quantitative literacy skills related to drug dosage practices could be started in the first year, as part of this module.

In addition, in response to the findings from Cycle I (discussed in Chapter 4), interventions focused on the understanding of intensive quantities and other difficulties (such as unit conversion and conversion between fraction types) were included in tuition.

Cycle II

2.6.3 Research Question 3

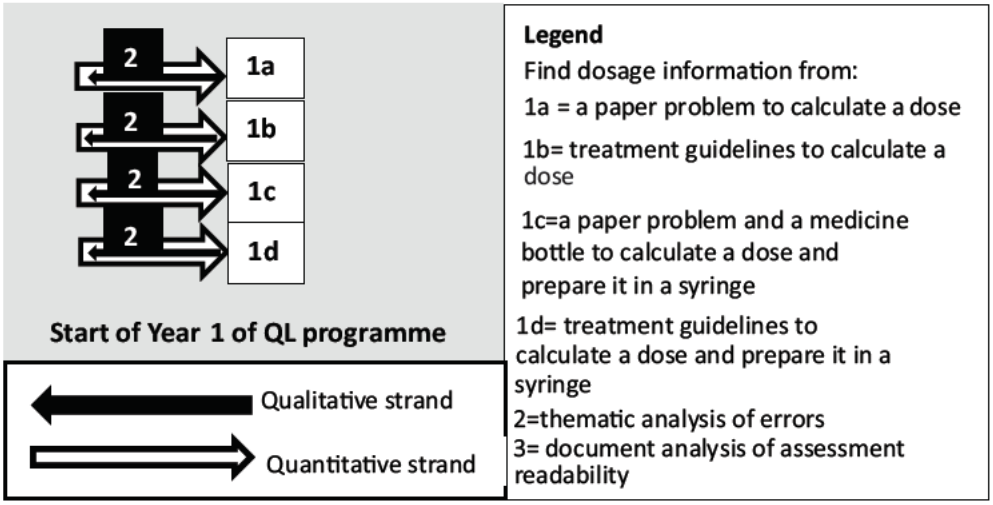
How does broadening a drug dosage practice task to include more workplace **contextual i**nformation change success?

2.6.3.1. Rationale

The analysis of student errors in Section 2.5.2.3 showed that the most common category, apart from omitting a question, was the category 'no idea'. For this category, the reasoning in student responses could not be followed or guessed at. Among these were 'crazy answers', where common sense should have made students realise that their answer could not be correct. One example of such a 'crazy answer' would be the volume of an injectable drug for a baby being larger than five litres, the blood volume of a typical adult. We believed that in the clinical setting, artefacts would provide contextual information, which would prevent students from making this sort of error and from actually giving a patient a dose that was some orders of magnitude too big or too small. Such artefacts would include the bottle or vial of formulation from which the volume of medication required was drawn, as well as the measuring equipment provided to draw up doses. We believed that providing such equipment as contextual cues during assessment and asking students to draw up the required dose for a patient would be one of the ways in which the task of calculating a drug dose could be made to align more with the skill as it was required to be carried out in the clinical setting. This was tested in an experiment that also tested broadening drug dose calculation assessment to include finding numerical dosage information from treatment guidelines, because before a drug dose can be calculated in the clinical setting, dosage details must often first be retrieved from guidelines and package inserts.

2.6.3.2. Mixed methods approach

Figure 2.3 Strands comprising aspects answering Research Question 3



This cycle was comprised of a qualitative strand that was embedded within a quantitative design.

2.6.3.3. Quantitative aspect

2.6.3.3.1 Design and procedures

A class of medical students beginning their dosage calculation tuition in their first year (after changes had been made to the curriculum and tuition programme) received tuition (as described in Section 2.2.2). and were then randomised into four groups. Students were all given the same scenario and asked to determine the required volume of a formulation of a drug in solution for a particular patient. Students would either be given dosage information about the medicine (Group 1 and 3) or would have to find this information in the formulary (Groups 2 and 4). The concentration of the formulation was then either provided in the paper problem (Group1), or on the label of a bottle of the formulation (Groups 3 and 4) or it had to be retrieved from an excerpt of a formulary (Group2 and 4). This numerical information could then be used to calculate the dose needed. Two groups of students who received the bottles of formulation (Groups 3 and 4) were also asked to prepare the required volume using a bottle of 'formulation' (the bottle in fact contained tea) and a syringe. Error frequencies were determined and associations were sought using Epi-Info (version 7.2.2.6) (Centre for Disease Control, 2011). Demographic factors were tested as possible predictors of dosing success. Associations were sought between those who retrieved numerical information from guidelines and those who did not, as well as those preparing a dose using dosage equipment compared with those who received no dosage equipment and who were asked only to calculate a dose

2.6.3.3.2 Measures of success

Students who were asked only to calculate the required volume for the fictitious case they received, were considered to have been successful if they wrote down the correct volume and unit (millilitres).

Students who were also required to prepare the correct volume in a syringe needed to perform this task correctly, in addition, in order to be considered successful. As each student 'answered only one question, i.e. 'treated' only one fictitious patient, the percentage of 'patients' receiving the correct treatment would be the same as the percentage of students correct. In order to measure students' ability to prepare a volume in a syringe, all students who correctly calculated and prepared the required volume, as well as those who drew up the dose they had calculated (though they had calculated the dose incorrectly) were considered to demonstrate the ability to measure a dose.

2.6.3.3.3 Methods of analysis

Epi-Info 7.2.2.6. (Centre for Disease Control, 2011) was used to assess whether there was any statistically significant difference in success between groups who retrieved embedded dosage information from guidelines and those who received typical paper problems. Data was also tested for an association between exposure to dosage equipment and success. For students retrieving dosage information from guidelines, those who showed competence were compared with those who were not successful to determine whether use of dosage equipment was associated with success. Demographic factors including gender, having English as a home language, matric score, previous school English and Mathematics success and academic success in the first year at medical school were tested as predictors of success or lack of success. school quintile (as a marker of socioeconomic status) South African government schools are divided into quintiles, with schools in quintile 1 serving communities with a socioeconomic status falling within the lowest 20%. Accordingly, school quintile was measured as a marker of socioeconomic success. The chi-square test was used for categorical data, while ANOVA was used to compare the numerical data of the mean school leaving score of successful and unsuccessful students. A p-value of less than 0.05 was considered to be statistically significant. Relative risks and their 95% confidence intervals (95%CI) were also calculated. (Details of this analysis can be found in Paper 3)

2.6.3.4. Qualitative aspect

This involved an exploratory thematic analysis of written calculation assessment responses. Students' written calculations were analyzed to determine, for incorrect responses what information had been successfully retrieved, and where the calculating process had broken down. Error types were categorised according to key themes which were developed as the analysis progressed. The analytical process followed was the same as was described in Section 2.6.1.4. and Section 2.6.2.3.2.

Cycle II competences required

Students were expected to be able to 1.) perform typical dosage calculations (as described in Cycle I), 2.) retrieve dosage calculation information from guidelines and formulation labels and 3.) prepare the quantities required of a formulation for administration (e.g. draw up the volumes of the doses they

calculated in a syringe or other form of dosage equipment). Success was measured as being able to demonstrate competence at a randomly assigned task involving some of these skills.

Cycle III

2.6.4 Research Question 4

What **proportional reasoning** skills do students demonstrate during drug dosage practices of increasing difficulty?

2.6.4.1. Rationale

The previous research questions initially concerned the task of calculating drugs (Research Questions 1 and 2). Research Question 3 then focused on extending this practice to consider those that are carried out immediately prior to and after this action, namely finding dosage information in treatment guidelines and actually preparing the dose calculated for administration to a patient. This Research Question explored the tasks that precede seeking dosage information: the quantitative thinking involved in rational drug selection and in helping patients understand the risks of different treatment options. Both of these require interpretation of the treatment risk statistics describing the efficacy of a treatment, in comparison to no treatment or a different treatment.

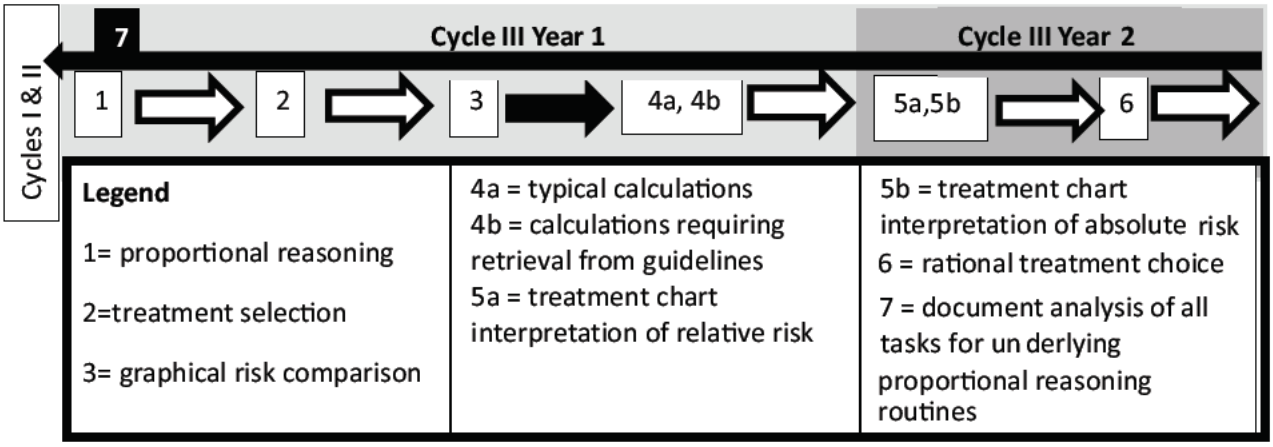
These practices involving making sense of treatment risk statistics were expected to be more difficult for students. These assessments required students to reason proportionately in the context of interpreting treatment risk statistics to make appropriate treatment choices. This task was cognitively more demanding and required more complex proportional reasoning compared with the task of drug dosage calculation. According to Bloom's Taxonomy (a tool which ranks cognitive thinking skills to support the design of appropriate educational assessments) calculating a drug dose is considered to be using knowledge (contextual and procedural) and understanding (for example, linguistic understanding and proportional reasoning) in a new way to solve a problem. The type of thinking that would be required would be 'applying', rated at Level 3 on Bloom's Taxonomy. Interpreting treatment risk information to make a rational selection would be considered to involve 'evaluating' information to make a decision based on set criteria, which is rated as an even higher cognitive skill level, at Levels 6 or 5 for the original and revised versions of Bloom's Taxonomy respectively (Krathwohl, 2002).
Students' success was compared with the competence they showed in their dosage calculation assessments to see if this was the case.

The proportional reasoning underlying each of the drug dosing practices that have been assessed in this cycle and in previous cycles was broken down, described and compared. The proportional reasoning needed to perform dosage calculation tasks involved 'missing-value type' routines, where three of the

four values in a proportion ***a/b = c/d*** are provided, and the student is required to calculate the fourth (Frith & Lloyd, 2016). In interpreting treatment risk statistics and making treatment decision, the proportional reasoning can be considered to be a combination of variations of 'comparison' and 'missing value' type problems. Comparison problems require the student to work out, when given four values (***a, b, c*** and ***d***), whether ***a/b*** is larger, smaller or equal to ***c/d***. Breaking down the workplace tasks and the students' assessment questions into individual proportional reasoning routines shows the level of complexity of the proportional reasoning required.

2.6.4.2 Mixed methods approach

Figure 2.4 Strands comprising aspects answering Research Question 4



The study design was comprised of a cohort study (Mathes & Pieper, 2007) assessing first year students' ability to perform simple proportional reasoning calculations, dosage calculations and the ability to interpret health risk statistics, to make a rational prescribing decision before and after health risk statistics teaching. In addition, there was a retrospective qualitative aspect, involving a document analysis of all the assessments in this cycle and in the previous two cycles, in which the proportional reasoning routines underlying the different calculations were described and compared.

The series of student assessments began with two quantitative strands, the first measuring proportional reasoning and the second, ability to avoid an irrational treatment selection (marked as 1 and 2 in Figure 2.4). This was followed by a qualitative aspect investigating the ability to compare risk represented graphically (marked as 3 in Figure 2.4) and ended with two quantitative strands involving dosage calculation (marked as 4a and b in Figure 2.4). In the next year, there are two quantitative strands. The first assessed the ability to interpret the treatment results chart reporting the findings of a randomised controlled trial to answer two questions, one about relative risk and one about absolute risk (marked as 5a and b in Figure 2.4). The second strand measured the ability to make a rational treatment selection (marked as 6 in Figure 2.4).

2.6.4.3 Quantitative aspect: basic proportional reasoning

Students were first assessed for lower level proportional reasoning and procedural rational number skills, which involved answering six 'proportional reasoning' questions before they had received training. The first three questions required reasoning of the 'missing values' type'. The remaining three questions tested lower level skills, namely fraction conversions and calculating the value of a percentage. They then received dosage calculation training and were assessed. The percentage of students who got all the questions correct, those who answered all three proportional reasoning questions correctly and those getting all the remaining procedural questions correct was determined. The proportional reasoning and rational number skills questions are included in Paper 4, *Can medical students make sense of treatment risk statistics?*. These students then received dosage calculation training and were assessed.

2.6.4.4. Quantitative aspect: formative assessment- avoiding irrational treatment selection

As part of treatment risk training, students were asked to make a treatment decision. First, students were given three statements, each involving a different treatment risk statistic format which, although students were not told this, described the same risk for the same drug. One statement provided the absolute risk information for placebo and treatment groups and the absolute risk reduction, another compared the risks in terms of relative risk reduction, and the third gave the number of patients that would require treatment in order to prevent one patient from having a heart attack (Number Needed to Treat or NNT). Students were asked to decide whether they would take a medicine based on the treatment risk information described in each of the statements. Details are included in Paper 4 *Can medical students make sense of treatment risk statistics?*. The statements and question are included in the Appendices.

Students were not asked to compare the risk, merely to consider each statement separately. (i.e. what would they do if they instead received the second or third piece of information about a treatment). However, as the statements actually described the same risk, they would need to make the same treatment choice for each statement if their treatment choices were to be rational. Saying they would take a treatment after considering the contents of one statement and that they wouldn't take another treatment on the basis of one of the other statements meant that their decision had been irrational. The percentage of students who decided differently depending on the risk statement was calculated. Although the remaining students could not be said to have made their decision because they had considered the risk statistics rationally (ie they might have been extremely open or averse to taking medication), a rational treatment choice was a possibility for this group. After responses were collected for an additional informal assessment (described below), it was revealed to students that the statements each described the same risk in different formats and they were shown how to manipulate the statistics from one form to another in order to compare them.

2.6.4.5 Qualitative aspect: formative assessment - graphical risk comparison

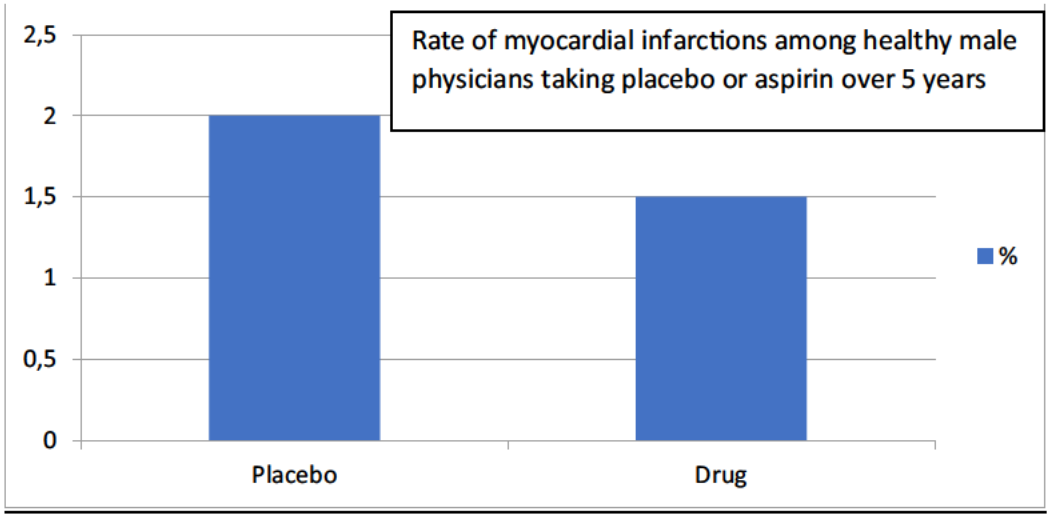
2.6.4.5.1 Rationale

Lloyd and Frith (2013) discuss a coping strategy of students, where they often apply learned rules and procedures for performing calculations involving difficult mathematical concepts without necessarily understanding the concepts. They may therefore be able work out a correct answer to a proportional reasoning question by rote rather than by reasoning proportionately. However, they may struggle to 'reason qualitatively' about information involving fractions that must be compared. In addition, therefore, a graphical assessment was included in order to assess students' 'proportional comparison' ability, the term used by Lloyd and Frith (2013) to describe the reasoning involved in comparison of fractions without doing calculations and with description of this reasoning in words. Using Lloyd and Friths' (2013) conceptual framework as a guide, students' responses were analysed according to what they revealed of their proximity to crossing the threshold to competent proportional reasoning.

2.6.4.5.2 Design and procedures

Students were given the following drug chart and some related questions. One of the questions they were asked is shown below.

"The following information is from a trial involving healthy male physicians taking a drug for 5 years to prevent heart attack. Use the information provided in the graph to answer the questions below".



Q1. Physicians taking the drug for 5 years have more/fewer (circle the most appropriate word) myocardial infarctions than physicians taking the placebo. I would describe this difference in detail as:

In a feedback session for the graphical question, students were subsequently shown how to represent the risk as three statements, each involving a different risk statistic.

The detailed written comparison that students provided produced a range of ways that they demonstrated reasoning. An analysis of students' written comments was conducted to categorise the types of reasoning students showed. This was used to create a map according to threshold concept theory (Meyer & Land, 2003), to determine what their responses revealed about where their reasoning was positioned in relation to crossing the threshold into competent proportional reasoning. This map was based on a framework for reasoning proportionately about percentage change represented graphically, created by Frith and Lloyd (2016). The percentage of students mapped at different stages toward reaching threshold competence was calculated.

2.6.4.5.3 Method of analysis

The categories in Frith and Lloyd's framework (2016) were used to develop preliminary categories to begin to think about and sort students' responses. This could be considered a deductive approach, as the researcher began to think about the data by fitting the information to a preconceived framework. However, if data did not fit, new categories were developed, and this was an inductive process. The researcher then looked at the responses and made a comment judging how the student was perceived to be reasoning. These were entered into an Excel spreadsheet.

2.6.4.6. Quantitative aspect: formal assessment – dosage calculations

2.6.4.6.1 Typical dosage calculations

Students received a varying number of dosage calculation assessments depending on the number of formal assessments they were required to write. The dosage calculation results of the students who wrote the final examination of the first year were analysed. Some of the dosage calculations (12 marks) included in the final examination of the first year were similar to test questions in the First Cycle and were analysed in a similar way. Students were deemed successful if they got at least one of the same four question types correct as was the case assessed in Cycle I. There were at least two questions of each type, so students had more opportunity to become successful in this assessment compared with the assessments in Cycle I which each included only one option of each question type. If each question presented to each student was considered to be a dosage calculation for a potential 'patient', the percentage of patients correctly treated could be calculated by adding the number of correct answers for each student and dividing the total by the product of the number of students and the number of questions (12) and expressing the resulting proportion as a percentage.

2.6.4.6.2 Calculations requiring retrieval of dosage information embedded in guidelines

The remaining 8 marks were four questions each for two cases which each required retrieving numerical information embedded in an excerpt from a different set of guidelines. This was the same type of question that was given to the students randomised to the 'guidelines only' arm in the second cycle. For the embedded questions, 10% got all eight questions correct, while 50% scored at least four questions correct, achieving competence at the 50% level. As there were two paper cases, each involving one 'patient' and with four questions related to it , students could treat two 'patients' correctly (by having all the questions correct), or one patient correctly, calculating correctly for all of one patient's scenario, but not having all correct for the other patient. Treating no patients correctly meant not getting all the questions correct for either patient. Even a student scoring six out of eight might have made one mistake for each patient and therefore neither patient could be considered to have received the correct treatment.

2.6.4.7. Quantitative aspects: formal assessments-interpretation of treatment chart and rational treatment choice

First, students were asked to interpret part of an event rate chart to determine different treatment risk statistics. Then they had to make a rational treatment selection when given three statements describing the efficacy for each of three different treatment options, each using a different risk format. They had to make a treatment choice from four options. One treatment option was more effective and therefore was the only rational choice. These assessment questions are included in Paper 4. The proportion of students who answered each of these questions correctly was determined as well as the number who answered all three questions, or the various combinations of two of the three questions correctly, or one of the three questions correctly.

2.6.4.7.1 Associations

Associations were sought using Epi Info (version 7.2.2.6) (Centre for Disease Control, 2011) to determine whether there were any predictors for making a rational decision (after tuition and formative assessment). Demographic factors were considered, including English home language, as well as measures of dosing practice success, such as basic proportional reasoning test success, dosage calculation competence, mean embedded calculation scores, attendance at the informal treatment selection assessment, position in relation to crossing the threshold to dosing competence and success in either of the treatment chart questions which involved interpreting treatment risk statistics. The relative risk and its confidence interval was calculated, to determine whether the difference in the proportions were statistically significant. The chi-square test was also applied to the data, with its p-value set at 0.05.

2.6.4.8 Qualitative Aspect: document analysis proportional reasoning routines in assessments

For all quantitative calculations in all the student assessments throughout the three cycles, the underlying proportional reasoning routines were broken down and described in terms of 'Missing Value' and 'Comparison' problem types. Those involving 'Comparison problems' were the kind where two ratios a/b and c/d had to be compared to see whether a/b was larger or smaller than c/d or whether the two ratios are equal. For the 'missing value' problem types, students would be given three values *a, b* and *c* and they would calculate the fourth *d* (Lamon, 2007). For the more complicated questions involving treatment risk, the nomenclature of Frith and Lloyd (2016) was used to describe the underlying proportional reasoning. They relate rates using the nomenclature $r1 = n1/d1$ and $r2 = n2/d2$.

Cycle III competences required

By the end of the preclinical years, students were expected to demonstrate the competences described in Cycles I and II, and also to be able to interpret treatment risk statistics correctly and to use these to make a rational treatment decision. Success for the proportional reasoning assessment (labelled 1 in Figure 2.4) was measured as answering three questions requiring proportional reasoning correctly. (This is discussed in Chapter 6, where the proportional reasoning demands of the questions are described. The questions asked are provided in Paper 4).

'Students who participated in the treatment decision assessment based on treatment statistics (labelled 2 in Figure 2.4, and described in Chapter 6 and Paper 4), were deemed successful if they made the same treatment decision for all of three health risk statements. Each statement described the efficacy of a treatment and each involved a different health risk statistic, but (unknown to the students at the time) these statements described the results of the same study.

For the qualitative evaluation (labelled 3 in Figure 2.4), successful students were those whose responses to a question (about a graph comparing trial results for a the risk of heart attack in a treatment group receiving a new drug and in a control group receiving placebo) were deemed to have crossed the theshold.to competent proportional reasoning. Students were deemed to have crossed the threshold if they described treatment risks correctly, one relative to the other, in a clear succinct way. The partial success of students showing aspects of proportional reasoning was ranked along a preliminal and then liminal pathway toward crossing the threshold to dosing competence (See Chapter 6).

Success for the typical dosage questions (labelled 4a in Figure 2.4) was deemed, as for the typical questions in Cycle I, as getting one of each of four types of dosage calculation question correct in a single assessment. For the dosage calculation questions requiring retrieval from guidelines (labelled 4b in Figure 2.4), students were deemed successful if they got all four questions correct for each of two cases requiring retrieval from different guidelines (See Chapter 8).

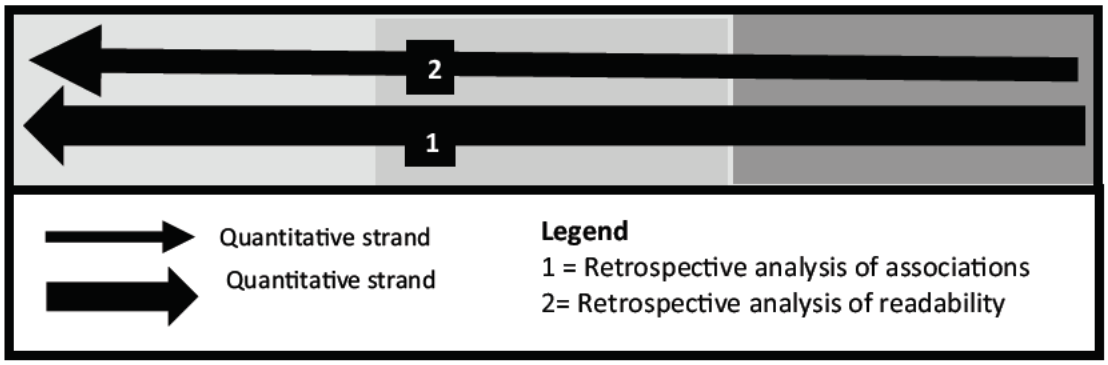
For the treatment chart (labelled 5a and b in Figure 2.4), the two measures of success were the percentage of students who successfully interpreted relative risk information (5a) and that of those who interpreted absolute risk information (5b) successfully. Finally, for the rational treatment choice assessment (labelled 6 in Figure 2.4), students were deemed to have made a rational treatment choice if they chose the most effective drug based on three statements, each describing a different treatment option and each involving a different treatment risk statistic.

2.6.5 Research Question 5

What **linguistic** skills and challenges do students demonstrate during drug dosage practices?

2.6.5.1 Mixed methods approach (quantitative only for this component)

Figure 2.5 Strands comprising aspects answering Research Question 5



This comprised two quantitative strands that were conducted retrospectively. The first strand involved exploring the association between home language and success in the different assessments, and the second strand assessed and compared the readability of the assessments used in the different cycles.

2.6.5.2 Associations with English as a home language

At the first assessment of dosage calculations with the first cohort students, having a mother tongue other than English was found to predict lack of success. Home language was associated with success in Cycle II, among the second cohort of students, as well as success in the final assessment –the rational treatment selection assessment –in Cycle III among the third cohort. Consequently, it was decided to make a retrospective analysis of all the assessments in the different cycles to explore the relationship between having a home language other than the language of instruction and failure to demonstrate success.

2.6.5.2.1. Associations

Associations were sought using Epi-Info 7.2.2.6. (Centre for Disease Control, 2011) and Excel together with the Two by Two Tables calculator at Open Epi (Dean, Sullivan KM & Soe; 2013).

2.6.5.3. Readability analysis

In addition, a readability analysis was made of all the assessments not yet scored for readability, and their Flesch reading ease score and its corresponding reading level was determined. Assessment of the readability enabled the linguistic difficulty of the assessment questions to be compared.

2.6.6. Research Question 6

What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?

Throughout their first year and part of their second year at medical school, the students in Cycle III (Cohort 3), received intermittent tuition, and were assessed for different drug dosage practice skills to determine what skills they could demonstrate and what needed attention during the rest of the preclinical years and beyond. This also served to some extent as an opportunity to see whether curriculum changes appeared to be benefiting students. First, a timeline of the different assessments and tuition that was conducted during the third cycle was described in tabular form. Next, these interventions were compared to those for previous cycles in a table. For interventions where similar assessments had been performed in previous years with a different student group, the findings of the assessments in Cycle III were compared to success in previous cycles. While the measure of typical dosage calculation competence was more readily compared between cohorts, the dosage calculations requiring retrieval of information from guidelines were compared between cycles according to readability, difficulty of proportional reasoning and other procedural arithmetic characteristics that were believed to contribute to the difficulty of the question. The demographic characteristics of the three cohorts were also compared to assist in drawing conclusions about success of the curriculum.
Finally, the table comparing Cycle 3 outcomes with previous cycle successes was used to consider study limitations and future lines of enquiry.

The next six chapters describe the results of the study, with one chapter for each of the six research questions. In each, the results of each aspect will be presented, showing how it contributes to answering the relevant research question. At the end of each chapter there are one or more research summary tables, relating the research aspects with the assessments the students participated in, how many students were involved and who they were (from which cohort they were drawn, which class of medical students they were in), what the main findings were and what contribution the results made to answering the research question.

CHAPTER 3 BRINGING DOSAGE CALCULATION TUITION TO MEDICAL SCHOOL

Research question 1

How successful are medical students in dosage calculations at the start of training?

This chapter presents the findings that answer the first research questions, as well as a results summary table (Table 3.3) at the end of the chapter.

3.1 Demographics

The majority of the 364 students in the study were women (59%). One hundred and eighty-seven (51%) spoke English as a home language. African students accounted for 50%, Indian students 40% and the remaining 10% were white or of mixed race. Of the 336 (92%) who had written the official South African school-leaving examination before entry to medical school, the average school leaving score was 44 (with a standard deviation of 5.6) out of a possible 50 points.

3.2 Student success

3.2.1 Proportion of students demonstrating competence

Of 364 participants, 23% were able to demonstrate dosage calculation success.
When competence was set at the 75% level, 47% of students were able to succeed.

3.2.2. Proportion of students displaying partial or no success

Table 3.1 shows the percentage of students who scored less than 100% in the assessment.

Table 3.1 Percentage of students achieving partial or no success

% questions answered correctly	**75**	**50**	**25**	**0**
% students receiving this score	24	22	15	16

3.2.3. Percentage 'patients treated' who would have potentially been harmed (received the incorrect dose)

Altogether, there were 727 mistakes from 1456 calculations. If each of the doses calculated had been given to a patient, 50% of patients would have received an incorrect dose.

3.2.4. Comparison of calculation types

Students struggled particularly with the problems involving concentration expressed in a ratio or percentage format, with 49% and 43% answering these questions correctly respectively. For the questions involving drip rate and mass per volume, 67% and 65% gave correct answers. There was a statistical difference ($p < 0.05$) between the first two and last two groups.

3.2.5. Associations

There was a significant difference in mean school-leaving score, with students deemed competent scoring three points higher, (scoring 46 points out of a possible 50 points compared with 43 points for students who did not demonstrate competence; p-value = 0.0001). Not having English as a home language was associated with lack of success (86% *vs.* 70%; relative risk 1.2; 95% CI 1.1-1.4). Gender was not associated with competence.

3.3 Error Analysis

This was combined with the error analysis in the next research question and is included in next chapter)

3.3. Readability of questions

Table 3.2 compares the readability and reading levels for each question type.

Table 3.2 Readability and reading level for each calculation type

Calculation Type	% of students correct (n = 364)	Flesch reading ease score	Reading level
Calculation of drip rate	67%	43.4	College level Fairly difficult to read
Drug concentration given as a mass per volume	65%	49.3	College level
Drug concentration given as a percentage	43%	64.4	Grade 8,9 Plain English
Drug concentration given as a ratio	49%	76.2	Grade 7 Plain English

The two groups of questions students found easiest, calculation of drip rate and calculation of concentration given as a mass per volume were found to be less comprehensible than the more difficult question, so comprehensibility did not account for their difficulty.

Table 3.3 Research summary

Research question: How successful are medical students in dosage calculations at the start of training?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Quantitative Cross-sectional study	Students worked out 4 dosage calculations (1 of each type) in a formal assessment	n = 364 3rd year students (Cycle I)	23 % 'full' competence* 47% competence at 75% level** 84% some level of success 50% potential 'patients' would have received the correct dose 67% students answered drip rate question correctly 65% answered mass/volume question correctly 49% answered ratio question correctly 43% answered percentage question correctly
Qualitative Thematic analysis	Researchers' analysis of responses: focussed on errors		Informed types of arithmetical mistakes being made (Combined with error analysis in next research question and included in next chapter)
Quantitative Document analysis of assessment questions	Researcher assessed the difficulty of the literacy task by determining and comparing the readability of the different assessment questions according to the Flesch reading ease score		The questions students had most trouble with (percentage and ratio questions) had better readability scores than the easier questions (mass/volume and drip rate) so linguistic difficulties did not explain the difference in success

* Included in Paper 1

** Included in Paper 2

CHAPTER 4 BUILDING DOSAGE CALCULATION COMPETENCE AT MEDICAL SCHOOL

Research question 2

What interventions improve medical students' success?

This chapter describes the findings of the aspects of the study that answer the second research question. At the end of the chapter, three research summary tables (Tables 4.16 - 4.18) present the summarised findings. Papers 1 and 2 follow, in which the quantitative findings are described.

4.1. Student success after further time and training at medical school.

4.1.1 Overall success

The 364 students in the study were the same as for Chapter 3 (the students that comprised Cohort 1). Student competence rose from 23% (82 students) at the start to 66% (239 students). There were 82 students who showed competence at the start (called Group 1, this was the group who were competent in the previous Chapter), 157 who became competent during the two years that they were assessed (called Group 2) and 125 who did not demonstrate competence in the two years (Group 3).

For Group 1, 36 students continued to answer all four question types correctly in subsequent tests, retaining their competence, while the other 46 students made 85 mistakes. In total, Group 1 students retained their competence 75% of the time while answering a total of 968 questions. If the questions are considered to be 'patients', then 9% of these 'patients' would have received the wrong dose. Although the 157 students in Group 2 were not competent to start with, they developed competence, showing competence 39% of the time. Altogether 664 incorrect calculations were made out 2156 questions answered (or 'patients' treated), meaning 31% of 'patients' could have been wrongly dosed. For Group 2 students, an average of three assessments were required to attain competence, with 88% becoming competent after to two or three assessments. Once they became competent, 87 incorrect calculations were made, out of 440, reducing the proportion of potential incidents of wrong dosing in a real-life situation to 20%.

For the final group of 125 students who did not become competent, they calculated 943 doses correctly of the 1908 questions they tried, but got 965 wrong, potentially negatively impacting 51% of their 'patients'. Altogether, the 364 students were competent 31% of the time, calculating the wrong dose for 34% of 'patients'. The findings for the three groups are summarised in Table 4.1.

Table 4.1 Cycle I Student Outcomes ($n = 364$)

Group (the number of students)	Students who were competent at the start	Fraction of time that the students were competent	Overall 'patients' receiving the wrong dose	Students retaining competence	Median Tests after competence (range)	'Patients' receiving the wrong dose after competence
Group 1 (82)	100%	75%	9%	44%	2(1-7)	13%
Group 2 (157)	0%	39%	31%	71%	1(0-4)	20%
Group 3 (125)	0%	0%	51%	N/A	N/A	N/A

N/A: not applicable

Competency was measured as getting each of four calculation types correct in a test

Each calculation represented a patient in real-life with the potential to receive an incorrect dose

Group 1 was competent at the start; Group 2 developed competence; Group 3 was never competent

There was a small statistically significant difference in mean school-leaving score of one point between students who achieved competence and those who did not, meaning the students achieving competence scored a mean of one symbol higher in one school subject ($p = 0.0046$). The higher risk of not achieving competence for students who did not speak English at home, reported for the initial assessment, was lost by the end (1-1.7).

4.1.2. Calculation types

When drug concentrations were expressed as a ratio and percentage, calculations were significantly more difficult for students than the mass per volume and drip rate calculations ($p < 0.05$). See Table 4.2.

Table 4.2 Percentage of time a particular type of calculation was wrongly answered (by definition the percentage of time a "patient" would have received the wrong dose)

Group (number of students)	Drug concentration given as a mass per volume	Drug concentration given as a percentage	Drug concentration given as a ratio	Calculation of drip rate
Group 1 (82)	5%	12%	13%	6%
Group 2 (157)	22%	38%	41%	21%
Group 3 (125)	37%	64%	64%	37%
Total (364)	25%	43%	44%	24%

Group 1 was competent at the start; Group 2 became competent; Group 3 was never competent

The average readability is compared for each question type in Table 4.3. Although the percentage and ratio question types were easier to read, they still presented more of a challenge for students.

Table 4.3 Average readability and reading level for each calculation type

Calculation Type	% of time answers were incorrect (n = 364)	Average Flesch reading ease score	Reading level
Drug concentration given as a mass per volume	25%	53.7	Grade 10-12 Fairly difficult to read
Drug concentration given as a percentage	43%	65.7	Grade 8,9 Plain English
Drug concentration given as a ratio	44%	70.9	Grade 7 Plain English
Calculation of drip rate	24%	52.6	Grade 10-12 Fairly difficult to read

Plain English is clear and concise and enables the reader to understand the message the first time they read it

4.2. Identifying strengths and barriers to progress

The contribution of the top three error categories to the total number of errors can be seen in Table 4.4, with 'Omitted' and 'No idea' contributing 55%.

Table 4.4 Top three error categories for dosage assessments responses (first year of tuition)

Error category	Omitted	'No idea'	Decimal error
Percentage of total number of errors	20%	35%	32%

Total number of errors 1714

n 364

For the stratified sample of students whose errors were most often categorised as 'Omitted' and 'No idea', 17 students were invited for observed individual tuition and 13 attended. For the weakest students, 38 were invited and 10 attended. Some demographic characteristics for these two groups are included in Table 4.5.

Table 4.5 Demographics for samples attending individual tuition (n = 13, n = 10)

Demographic factor	Female gender	English home language	Passed latest formal assessment	Supplementary Examination
Stratified group	54%	31%	62%	15%
Weakest group	60%	10%	80%	30%

The first four key themes into which observed individual tuition case notes were coded will be discussed in this section.

They are as follows:

Student abilities;

Student difficulties

Student behaviour communicating lack of competence

Problems with learning interactions or assessments

4.2.1. Student Abilities

Case notes of the observed individual tuition was analysed for evidence of any student ability relating to calculating dosages correctly. These 'references' were coded, resulting, for the stratified sample, in the development of seven subcategories for this theme. Codes for the case notes of the sample of students with weak calculation skills were also identified, with five of the seven subcategories above, as well as an additional eight subcategories. The subcategories for the two samples, as well as the identifying number for students coding for these are described in Table 4.6.

Student were coded for 'Number agility' if they displayed a flexibility with numbers, an ability to manipulate numbers or see patterns. Lipkus et al. found that conversions from one format to another, for example converting frequencies to percentages were most difficult for people scoring poorly in the numeracy test they designed (Lipkus et al., 2001). This ability was coded seven times, the most frequently coded from the case notes of the stratified sample. Student 2 shows five other abilities. Only student 6 was not coded as showing any ability. For the sample comprising the weaker students, only three students displayed number agility.

Table 4.6 Student abilities during individual tuition (n = 13, n = 10)

Ability	Stratified sample	Number of students stratified sample (identifying number)	Sample of weak students	Number of students weak skills sample (identifying number)
Can work out mg/kg		3 (2,7,11)		n/a
Pragmatic ability demonstrated		2 (1,2)		
Number agility/comfortable playing with numbers		7(1,3,4,5,9,10,11)		3 (16,17,21)
Cross-multiplies correctly		5 (2,7,8,9,12)		5 (15,16,17,19,20)
Able to convert g to mg		4 (7,11,12,13)		3 (17,20,23)
Algebraic logic shown		3 (2,9,12)		5 (16,17,19,20,21)
Can picture to some extent the information described		2 (2,4)		3 (16, 18,21)
Knows meaning of %		n/a		2 (14,16)
Understands that concentration relates to strength of solution				2 (14,16)
Knows meaning of 'reconstituted'				2 (16,18)
Knows drip rate formula				2 (20,23)
Simplifies by crossing off 0's both sides of equation				2 (20,23)
Knows units for concentration expressed as %				2 (21,23)
Knows the units for concentration expressed as a ratio				1 (20)

Each student in the stratified sample were given a unique identifying number from 1 to 13.

Each student in the sample with weak skills were given an identifying number from 14 23

4.2.2. Student Difficulties

Case notes from the observed individual tuition of both samples were coded for evidence of student difficulties. Difficulties in the case notes were noted as 'references' and were each grouped into codes. These codes are listed in Table 4.7 below. Twenty four codes relating to 'difficulty' were identified from the case notes of the stratified sample, and twelve of these also pertained to the sample of students with weak dosing skills. The most frequent difficulty for both samples was 'Formula problems', which was coded for every student from the stratified sample, sometimes several times, to give 20 references, making it the most frequent difficulty. 'Formula problems' included problems converting a concentration given as a percentage or a ratio into the mass/volume format e.g. 'a 1% solution is 1 g in 100 mL' or 'a 1:1000 ratio is 1 g in 1000 mL', as well as problems remembering the formula for working out the drip rate required. Eight students from the sample with weak skills also coded for this difficulty, (with 18 references) but two students, students 21 and 23, were able to recall the units. For the stratified sample, the next most frequently coded (8 students, 12 references) were difficulties with unit conversions, e.g. converting grams to milligrams or micrograms to milligrams. For the sample with weak skills, 'unit conversions' was third most frequently coded (7 students, 10 references). Five students from the stratified group and three students from the weak group also thought that conversion between milligrams and grams or millilitres and litres involved multiplying or dividing by 100 instead

of 1000. For the stratified sample, third most frequently coded (7 students, 9 references) were difficulties with algebraic logic, while for the sample with the weaker skills, the second most frequently coded subcategory was overreliance on a calculator (8 students, 9 references).

The six students from the stratified sample (Students 2, 6, 7, 8, 12 and 13), and the seven students from the sample of the weakest students (Students 14, 15, 18, 19, 20, 22, 23) who did not display the ability 'number agility' were expected to be the students with the least developed arithmetical skills, and grouped together. The four students from the stratified sample (students 1, 3, 5 and 10), and the three students from the group showing the weakest skills (students 16,17 and 21) who displayed number agility and who did not have difficulties with either algebraic logic or with unit conversions were grouped together as the students with the most developed arithmetical skills. The three students from the stratified sample who displayed number agility but who had difficulties with both unit conversions and algebraic logic (students 4, 9 and 11) were grouped as showing an intermediate level of arithmetic capability. None of the students in the sample of weaker students fulfilled these criteria.
The difficulties experienced by each student are listed, grouped according to presumed ability according to these criteria, in Table 4.7 below.

Table 4.7 Difficulties experienced by students grouped according to abilities

Difficulty			**No. of students (no. of references)**	**Least skills Stratified:** 2;6;7;8;12;13 **Weak:** 14; 15; 18; 19;20; 22; 23	**Intermediate skills Stratified:** 4;9;11	**Most skills Stratified:** 1;3;5;10 **Weak:** 16;17;21
Formula problems			A:13(20) B:8(18)	A: all B:14;15;18;19;20;22	All	A: all B:16;17
Difficulty with unit conversions 1000 not 100			A:8(12) B:7(10) A:5(7) B:3(3)	A:2;6;7;8 B:18;19;20;22 A:2;6;12 B:14;18	All 11;9	A:3 B: all n/a B16
Difficulties with algebraic logic			A:7(9) B:2(3)	A:2;6;7 B:14;18	All	A:10 n/a
Overreliance on calculator			A:4 (11) B:8 (9)	A:2;7;8 B:14;15;19;20;22;23	4	n/a B:16;17
Lack of number agility or ease with numbers			A:4(10) B:2(2)	A:2;7;8 B:14;20	9	
Carelessness			4(7) 2(2)	A:7 B: 19	11	A:1;10 B: 16
Problems cross-multiplying or with method for solving equations			A:4 (4) B:1(2)	A:2;6;12 B:15	9	n/a
Problems with intensive quantities e.g relationship between mg and mL			A:3(3) B:7(12)	A:2;7 B:14;15;18;19;23	4 n/a	n/a B:16;21
Converting fractions from one form to the other			A:3(4) B:1(1)	A:2;8;12 B:17		n/a
Caught by red herring			A:2(3) B:4(5)	A:8 B:14;18;19		A:1 B:16
Problems with hundreds tens and units			A:2(2) B:4(4)	A:8;12 B:15;19;22;23		n/a
Difficulty with meaning of %			A:1(1) B:1(1)	A:7 B:15		n/a
Problem with concept of concentration expressed as %			4 (4)	15;18;19;23		n/a
Misunderstood the expression 'dilute to 10 mL'			4(4)	2;6;7		5
Misread question			3(3)	2	9	10
Inability to simplify			2(2)	7;8		n/a
Problem with concept of ratios			2 (2)	14		16
Inefficient method e.g. failed to see utility of simplifying complicated units			2(2)		4;9	
Problem converting mg/kg dose to mg dose			1(2)	8		n/a
Not familiar with vocabulary used			1(1)	2		n/a
Lack of pragmatic ability			1 (1)	18		n/a
Problem converting units of time			1 (1)	23		n/a
Difficulty interpreting meaning of the question			1(1)			3
Slow, lack of fluency			1(1)		9	

Students not showing number agility least promising, those showing number agility + algebraic logic difficulties +/or unit conversion difficulties intermediate, those showing number agility +no algebraic logic difficulties +no unit con version difficulties most promising. A stratified; B weak

4.2.3. Student behaviours communicating lack of competence

Observation of the tuition revealed eleven behaviours or emotions that were communicated in relation to experiencing a lack of competence. These were most commonly identified during the early part of the tuition as students tackled their first questions. Of the 23 students, twelve displayed signs attributed to feeling a lack of competence at the start of the tuition. For the majority of these twelve, more than one type of behaviour was displayed. Nearly a third of the mixed-ability sample showed these behaviours, while for the weakest student sample, 80% seemed to be experiencing these uncomfortable feelings.

Table 4.8 Feelings associated with feelings of incompetence at the start of individual tuition

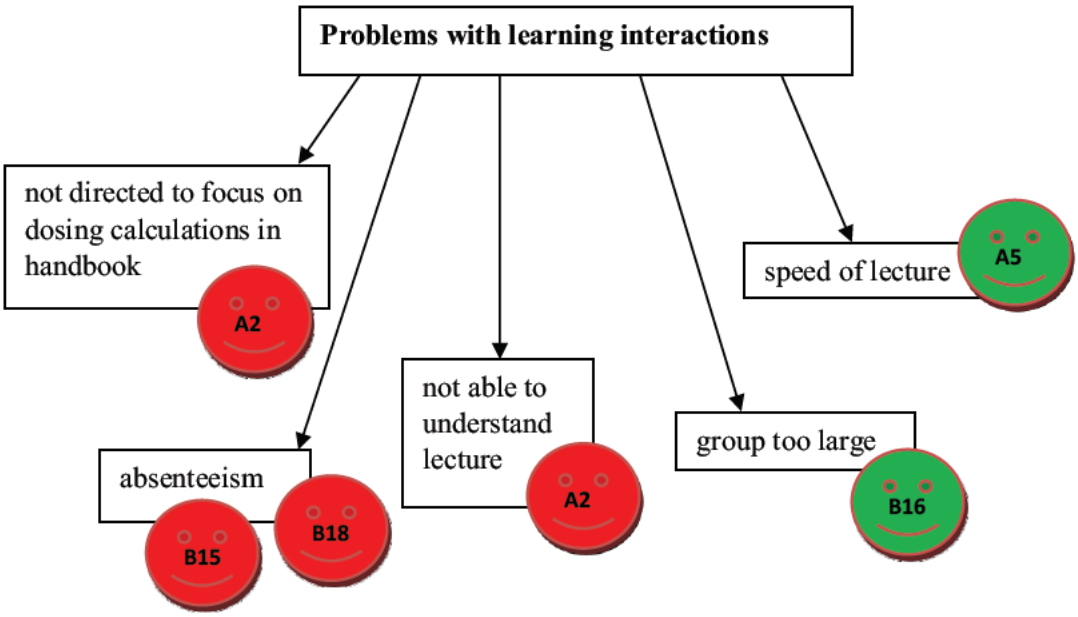
Feeling or behaviour communicated	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	B 14	B 15	B 16	B 17	B 18	B 19	B 20	B 21	B 22	B 23
Shame		y																					
Hesitancy		y					y	y	y					y		y				y			y
Researcher feeling a connection has not been made							y											y					
Anxiety																y		y					
Dislike calcs																	y						
Expressed need of support																		y					
Feeling lost																		y					
Unsure																				y			
Struggle to understand														y	y							y	
Sense of resignation														y				y					
Lack of insight into own lack of competence															y		y						

A stratified sample of students B sample if students with the weakest skills y yes

4.2.4 Problems with learning interactions or assessments

Two students from the stratified group expressed problems with the learning interactions: they felt they were unable to benefit from the lecture due to speed or language problems. One of these students felt the handbook did not direct students sufficiently towards the importance of focusing on dosage calculations. Three students from the sample of the weakest students had learning interaction-related problems: two missed the lectures and the other student felt the lecture group was too large. These relationships are shown in Figure 4.1 below.

Figure 4.1 Students experiencing different problems with learning interactions

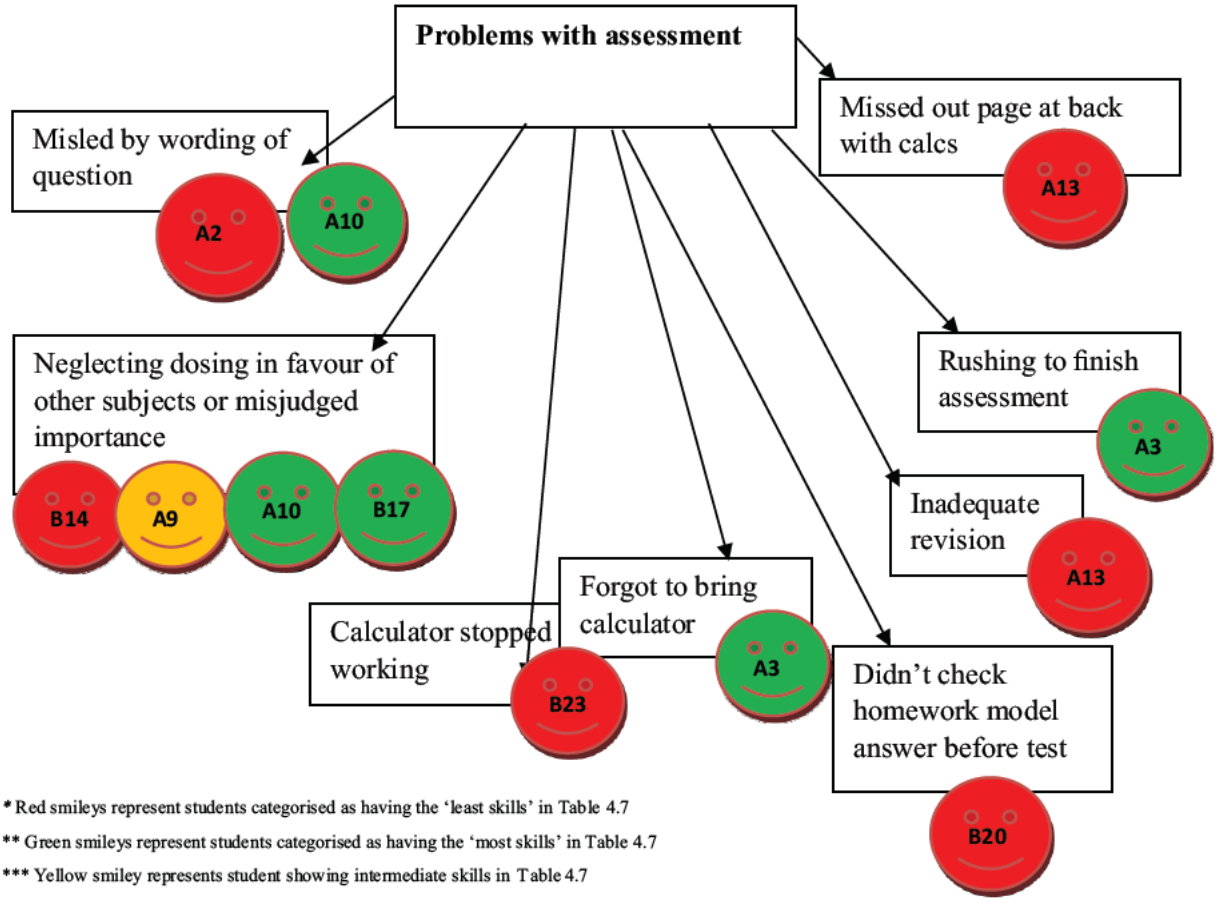


* Red smileys represent students categorised as having the 'least skills' in Table 47

** Green smileys represent students categorised as having the 'most skills' in Table 4.7

Five students from the stratified group and four students from the sample of the weakest students felt the assessment problems did not allow them to reflect their true calculation ability. Two students from each group had neglected dosing in favour of other subjects, misjudging the importance of focusing on calculations and felt inadequately prepared. This relates to one of the learning interaction problems, that of feeling inadequately directed by the handbook toward the importance of focusing on dosing. One student from the stratified sample admitted not having tried the examples before the first assessment, while a student from the sample of weak students tried the examples but did not check these against the model answers before the assessment. Two students from the stratified sample felt misled by the wording of one of the questions and felt it could have been worded in a clearer way. One student from the stratified group said he had been rushing and had had insufficient time to focus on the calculations; he had also panicked when he discovered he had forgotten his calculator (although he was able to cope with the arithmetic without a calculator in the interview). Similarly, a student from the sample of weak students panicked when the calculator got stuck. Finally, a student from the stratified group forgot to turn the paper over to the back page containing the calculations and so left them out. These categories and the students coding for them are shown in Figure 4.2.

Figure 4.2 Students experiencing different difficulties related to assess ment



* Red smileys represent students categorised as having the 'least skills' in Table 4.7

** Green smileys represent students categorised as having the 'most skills' in Table 4.7

*** Yellow smiley represents student showing intermediate skills in Table 4.7

4.3. Support to overcome the barriers

The remaining key themes identified in the observed individual tuition case notes relate to support and overcoming barriers to build competence. These three themes are as follows:

Strategies to overcome difficulties;

Suggestions for improvement of learning interactions or assessment; and

Experience of developing competence

4.3.1. Strategies to overcome difficulties

During the observed individual tuition, as students tried the dosage calculation questions they had got wrong in their tests and examinations and got stuck, the teacher would offer some sort of prompt or guidance to assist them to overcome the stumbling blocks and keep going. These strategies for overcoming difficulties suggested by the teacher were sometimes later used unprompted by the students. The types of prompts or strategies offered, and those taken up unprompted by students are listed in Table 4.9.

Table 4.9 Teacher encouragement and student use of strategies to overcome difficulties †

Strategies	Subcategories		Identifying number of student offered encouragement	Identifying number of student using strategy
Ways to avoid cross-multiplying problems (the 'two column stepwise method')			2;9	2;6
Convert the units that avoid using decimals			2, 11	0
Think of a simpler/more accessible model when faced with a more complicated one			2	0
Strategies to convert units	'Bunny jumps'* to find out where the comma goes		7, 12	12
	'King Henry Died of a Miserable Disease Called Measles'**		11	0
Strategies to avoid carelessness	Write down working out		1, 2	1
	Include units in working out		2	0
	Check working out	Stratified sample	A:11 B:16	0
Value of a diagram			A: 4;5;7;8;9 B:all students	A:2;8;11 B:14-18, 21;23
Check to see answer makes sense			A:9;10 B:16;18	A:1 B:0
Forgotten formula: Use units to guide from first principles			19;22	0
Use a revision sheet with key information			18;15	0
Try working out sum without a calculator			14	0
Picture the information in real life			16	0
Compare with something more familiar			16	0
Unit x 'per unit' cancels out			16	0
Try a different teaching approach/teacher			18	

A stratified sample B sample of weakest students

*"bunny hops': when converting from larger to smaller units 'hop' the comma three places to the right and put a zero under each 'hop' 3 g → 3 000 mg

when converting from smaller to larger units think of the 'invisible comma after the last digit and 'hop' the comma three places to the left

so 3000 mg→ 3000 , mg ⟶ 3 ggg , mg ⟶ 3 , 000 g ⟶ 3 g

** 'King Henry Died of a Miserable Disease Called Measles' is a mnemonic for the descent by factors of 10 of the metric measures kilo-, hecto-, deca-, metre, deci-, centi-, milli-

†included in Presentation 1

4.3.2. Suggestions for improvement of learning interactions or assessment

During the individual tuition students were asked how they thought students could be better prepared for calculating drug doses in their clinical years and when qualified.

Student suggestions included:

early assessment and remedial follow-up for struggling students (Student A2)

including calculations in the learning goals (Student A2)

lecturer-marked tutorials (Student A1)

dosing to be a compulsory skills session (Student B18)

initiation of a gateway calculation test where a student would have to get 100% before obtaining their medical degree. (Student 21)

more examples to be provided (Students 14,19,22)

lecture improvements:

(Student A2) "emphasize that there is a formula that has to be learnt that 1% (*a 1% solution)* = 1/100 mL" and "explain what amp and vial mean"

Smaller interactive groups (Students 16, 23)

assessment improvements:

(Student A2): avoid using differing terms (e.g. amp and vial) to refer to the same thing

Researcher suggestions included

providing students with a 1-page fact sheet with key information such as

1% = 1g/100 mL and 1:1000 = 1g in 1000 mL; there are 1000 mg in 1 g and 1000 mcg in 1 mg;

emphasize calculations in the learning goals (they had been included)

provide pictures of vials and ampoules or samples of these in the lecture (the difference had been explained in words only)

explain the difference between 'dilute to 10 mL' and 'dilute with 10 mL'

4.3.3. Experience of developing competence

At the start of the individual tuition nine students showed evidence of some existing mathematical ability. Some of these required only a small amount of guidance, such as being told that the units in a 1% solution were grams per 100 millilitres. After this they were able to calculate skilfully and confidently. Twelve students showed the discomfort their lack of competence caused them as listed previously in Table 4.8. As they received guidance and were able to proceed with their calculation successfully, some students appeared to look more comfortable and relaxed and required less guidance. Some proceeded to being able to calculate subsequent questions independently. Some students seemed to have an attitude or behaved in ways that seemed to support their learning or assisted the teacher to help them become successful: these behaviours are shown in Table 4.10. A few students went all the way from displaying very poor skills and appearing very uncomfortable with dosage calculations to sorting out their incorrect understanding to working through later questions successfully and appearing to have lost some of their anxiety around facing calculations. Student 2, for example, appeared shameful and hesitant at the start of her individual tuition. She showed a willingness to engage with the questions and try, and she asked questions which helped the guide to know how to help her. By the end she was able to calculate a dose successfully without guidance or a calculator. A summary of the students' progression is shown in Table 4.11.

Table 4.10 Students displaying beneficial behaviours

(may help them benefit from the guiding relationship experienced during individual tuition

	Student identifying number																						
Feeling or behaviour communicated	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	B 14	B 15	B 16	B 17	B 18	B 19	B 20	B 21	B 22	B 23
Willingness to try a problem		y												y		Y							
Eagerness to learn (prepared to listen to reasoning)																Y							
Insight into current lack of competence																Y		y					
Asking questions		y	y			y			y			Y	y	y		Y				y		y	
Motivation from experience of success														y		Y			y				
Expressed need for support																		y					
Feeling better										Y													

A stratified sample of students B sample if students with the weakest skills y yes

Table 4.11 Students' change in behaviours during individual tuition with growing confidence

(as they became more successful at answering questions and required less guidance)

Behaviours associated with competence as the individual tuition progressed	**Student identifying number**																						
	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 9	A 10	A 11	A 12	A 13	B 14	B 15	B 16	B 17	B 18	B 19	B 20	B 21	B 22	B 23
Initial number of feelings/ behaviours associated with lack of competence (details in Table 6)	0	2	0	0	0	0	2	1	1	0	0	0	0	3	2	2	2	5	0	2		1	1
Presence or absence of initial feelings/behaviours associated with competence	p	a	p	a	p	a	a	a	a	a	p	A	p				p		a	p	p		p
Behaviours communicating developing competence (details in Table 8)	1	2	1			1			1	1		1	1	3		5		2	1	1		1	
Behaviours communicating developed competence by the end of the individual tuition	1	1	1		1	1	1	1	1		1		1			1	1	1	1			1	

p present a absent, grey columns show the students who moved from communicating lack of competence to communicating competence

4.4. The effect of support on students' ability

4.4.1. Benefit of time and practice

Of the 364 students, 282 were not found to be competent at the beginning of their third year. At the end of their third year though, 56 (21%) had developed competence. For the 224 students who had not yet developed competence, 99 (44%) did so by the end of their last test in the fourth year. This meant that more students succeeded during the fourth year than the third year of study. The same conclusion was reached when students' competence was measured at the 75% level, with 30% and 55% of students achieving success by the end of the third and fourth years respectively. The number and percentage of students competent by the different screening stages are shown in Table 4.12. Incorrect calculations involving concentrations expressed as a ratio or percentage accounted for most of the mistakes that prevented students who reached 75% competence from attaining 'full' (100%) competence.

Table 4.12 Number and percentage of students competent over time (n = 364)

Screening stage	Number competent at		Number not yet competent at		Percentage competent at		Percentage newly competent at	
	100% level	75%level	100% level	75% level	100% level	75% level	100% level	75% level
Start of 3rd year	82	172	282	192	23%	47%		
End of 3rd year	140	232	224	132	38%	64%	21%	30%
End of 4th year	239	305	125	59	66%	84%	44%	55%

n number of students

4.4.2. Benefit of opportunities for same home language peer learning

For a sample of 200 fourth year students who had assessments both before and after the fourth year tuition, the fourth year tutorial increased ability, with competence at the 75% level improving by 10% in attendees and decreasing by 3% in non-attendees, the benefit being attributed to collaboration between same-language peers in small groups. The comparison of the percentage of students competent before and after the tutorial is shown in Table 4.13.

Table 4.13 Percentage of students competent before and after peer learning intervention (n = 200)

Screening stage	Attendees (n = 83)		Non-attendees (n = 117)	
	100% competence	75% competence	100% competence	75% competence
Start of third year	14%	34%	11%	43%
End of third year before intervention	30%	55%	21%	53%
End of fourth year after intervention	30%	65%	24%	50%

4.4.3. Benefit of closer contact with faculty through one-on-one tuition

Individualised assistance offered to the struggling students during one-on-one tuition also resulted in improvement. For the mixed-ability group of students (n = 13), three students did not attend the final assessment. For the remaining ten students, all were able to attain 100% competence in their final assessment. Among the weak sample of students, three did not complete the final fourth year assessment. For the remaining seven, although only one attained 100% competence, with an additional one reaching competence at the 75% level, all six students who had not got a single dosage calculation correct by the end of the year, managed to get at least one calculation correct. Tables 4.14 and 4.15 give the dosage results for the students at different stages during the course of the tuition.

Table 4.14 Dosage results for the stratified sample of students given individual tuition

Score achieved	0%	25%	50%	75%	100%
Beginning of third year (n = 13)	6	4	3	0	0
End of third year (n = 13)	4	4	4	1	0
End of Fourth year (n = 10)	0	0	0	0	10

n number of students

Table 4.15 Dosage results for the sample of weakest students

(n = 10; three not included in the final assessment)

Score Achieved	0%	25%	50%	75%	100%
Beginning of third year (n = 10)	6	3	1	0	0
End of third year before intervention (n = 10)	6	3	1	0	0
End of fourth year after intervention (n = 7)	0	1	4	1	1

n number of students

Students receiving individual tuition provided feedback which allowed the teacher to be responsive to their particular learning needs and tailor appropriate strategies. The tuition also offered an opportunity for the teacher to diagnose problems relevant to the class as a whole. The strategies that assisted individual students could be used to adapt the curriculum for these students as they continued into their fourth year, and for future students, so these issues could be pre-empted and would hopefully result in less students struggling for so long before receiving the guidance they needed.

4.5 Consequences arising from the findings

Observation of these 364 students led to the curriculum change from the start of the following year as described in Chapter 2. Dosage calculation tuition was shifted to the start of the first year where it was given additional contact time spread throughout the year and included in formal assessments. The contact time included revision of decimals, conversion of units and procedural issues that had been found to be problematic. Visual examples of the equipment involved in dosing patients, such as the vials and ampoules, administration sets and minibags were included in lecture slides and the concept of concentration was explained with some of the analogies that had been used in the individual tuition sessions, while the meaning of percentage and ratio solutions was emphasised. In the two years that followed, two first year classes were studied. In addition to being taught how to work out typical dosage

calculations, their training was extended. They were assessed for their ability in typical dosage calculations as well as in other drug dosage practice tasks (which forms the content of other chapters).

Table 4.16 Quantitative research summary

Research question: What interventions improve medical students' success?

Research type	Task undertaken by the students or researchers	Sample academic level (n)	Contribution to the understanding/resolution of the problem
Quantitative **Cohort study** longitudinal following students over two years and observing change in dosage competence by assessing dosage calculation competence in formal assessments	Students worked out 4 dosage calculations (1 of each type) in formal assessments over two years	n = 364 3rd year students (Cycle I)	Cumulative competence At start End 3rd Yr By end *100% level:* 23 % → 38% → 66% ** *75% level:* 47% → 64% → 84% ** *some level of success:* 84% → 99% *'patients' correctly dosed:* 50% → 66% Question types correct: At Start By end Drip rate 67% → 76% Mass/volume 65% → 75% Ratio 49% → 56% Percentage 43% → 57% **Findings provide evidence of students' improvement and helps teacher gauge how far students and curriculum development still must go until all students leave the preclinical years competent** *% students newly competent* End 3rd Yr End 4th Yr** *100% level:* 21% → 44% *75% level:* 30% → 55% **Findings provide evidence of benefit of time and practice**
Quantitative **Controlled before –after experiment**	Students had the opportunity to attend small group work tutorial in the 4th year Students worked out four dosage calculations in formal assessments before and after the tutorial	n = 200 3rd year students (Cycle I) who were formally assessed shortly before and after 4th year intervention	Before After Tutorial attendees: *100% level:* 30% → 30%** *75% level:* 55% → 65%** Tutorial non-attendees: *100% level:* 21% → 24%** *75% level:* 53% → 50%** **Findings provide evidence of benefit of peer learning**
Quantitative	Students attended individual tuition Researchers measured cumulative number of correct calculations in formal assessments before and after tuition	Stratified group n = 13 and Weakest group n = 10 3rd year students (Cycle I)	End 3rd Yr End 4th Yr Stratified: (n = 13) (n = 10) *100% level:* 0 → 10 students ** *75% level:* 1 → 0 students** Weakest (n = 10) (n = 7) *100% level:* 0 → 1 students** *75% level:* 0 → 1 students** *50% level:* 1 → 4 students** *25% level:* 3 → 1 students ** *0% level:* 6 → 0 students ** **Findings provide evidence of the benefit of individual tuition for struggling students**

** Included in Paper 2

Table 4.17 Qualitative research summary

Research question: What interventions improve medical students' success?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Qualitative **Thematic analysis** of responses	Researchers categorised calculation errors in all dosage calculation responses in 3rd year formal assessments	*n* = 364 3rd year students (Cycle I)	**Top three error categories** 'No idea' 35% Decimal error 32% Omitted 20% **Informed types of arithmetical mistakes being made** **Informed selection of students for one-on-one observed tuition (to understand the omitted and no idea categories**
Qualitative **Observation of one-on-one tuition → thematic analysis** of teaching interaction	Students worked through the calculations they had got wrong in formal assessment, teacher assisted when student got stuck. Students were asked if they had any problems with the tuition and assessment	Stratified group *n* = 13 and Weakest group *n* = 10 3rd year students (Cycle I)	*Observation and interaction:* Researchers identified student strengths, and mathematical processing and affective difficulties communicated by students **Top Strengths** number agility (played with numbers) (10 students), cross-multiplied (10), showed algebraic logic (8), converted from g to mg (7) **Top mathematical difficulties** Formula problems (21 students) Unit conversions (15), Overreliance on a calculator (12) Difficulties with algebraic logic (9) **Behaviours communicating uncomfortable feelings due to lack of competence** Shown by 31% of the mixed-ability group and 80% of the weak group Most common of these (8 students) was hesitancy *Interview:* Students identified problems with tuition or assessments Some tuition problems (speed of lecture, group too large, not able to understand lecture) could be result of difficulties due to language or feedback with large group sessions Assessment problems; half due to inadequate revision; also (2 each) inadequate time, overreliance on a calculator, language related **Findings assisted in pitching tuition appropriately, informing curriculum change and assisted teacher to choose strategies to overcome individual student's difficulties and to develop student's learning**

Table 4.18 Qualitative research summary continued

Research question: What interventions improve medical students' success?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Qualitative **Observation of one-on-one tuition → thematic analysis** of teaching interaction	Students worked through the calculations they had got wrong in formal assessment, teacher assisted when student got stuck. Students were asked if they had any problems with the tuition and assessment	Stratified group $n = 13$ and Weakest group $n = 10$ 3rd year students (Cycle I)	*Observation and interaction*† Researcher offered and students took up strategies chosen to overcome difficulties. They showed attributes that assisted guidance and some moved from communicating lack of competence to communicating competence **Strategies taken up (number offered → number taking up)** Draw a diagram (15→10) 2 column stepwise method (2→2) Ways to avoid carelessness (5→1) Check answer makes sense (5→1) Ways to convert units (3→1) **Student attributes that assist guidance** Asking questions (10 students), motivation from experience of success (3), insight into lack of competence (2), willingness to try problem (2) **Experience of developing competence** 15 students communicated developed competence. 8 of these had initially communicated a lack of competence *Interview:* Suggestions for improvement of learning interactions or assessment made by student or teacher have informed curriculum change

†Included in Presentation 1

Can medical students calculate drug doses?

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Keywords: drug dosage calculations, clinical competence, medication errors

Abstract

Objectives: A doctor's ability to calculate drug doses is a skill that is generally assumed. We assessed medical students' performance when given four types of dosing calculations typical of those required in an emergency setting.

Design: Longitudinal study.

Setting and subjects: Students were assessed at the beginning of the third year, and repeatedly during the third and fourth year while receiving training in dosage calculations. Competence was defined as correctly answering all four categories of calculation at any one time, i.e. a score of 100%. Failure to respond correctly to the individual questions was also analysed because an incorrect calculation could be equated with a "patient" receiving a wrong dose.

Outcome measures: Outcome measures were the percentage of students achieving competence and the proportion of times students showed competence relative to their total number of opportunities. A further outcome was the percentage of calculations incorrect i.e. potential "patients" harmed.

Results: Of the 364 students, 23% were competent at the beginning, while 66% achieved competence at least once by the end of the study. Students were competent 31% of the time and calculated the wrong dose for 34% of "patients". Eighty-two students were competent at baseline, 157 became competent and 125 never achieved competence. They calculated the wrong dose for 9%, 31% and 51% of "patients" respectively. Although race and home language were predictors of performance at baseline, both associations had been lost by the time competence was achieved. All students experienced the most difficulty with calculations when the drug concentration was expressed either as a ratio or a percentage.

Conclusion: Our findings support calls for the standardised labelling of drugs in solution and for dosage calculation training in the medical curriculum.

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Introduction

Medicine errors, which affect 50% of hospital admissions, are a source of morbidity and mortality in patients worldwide.[1,2] Prescription writing was the worst performed skill of those tested, with an achieved score of 55.3% in a South African study of students who had graduated, but not yet registered.[3] Errors in administration, particularly those relating to dosing, were one of the key findings in a UK report by the National Patient Safety Agency.[4] It is important that attention is paid to trying to ensure that drug doses are calculated correctly. Prescribers recognise this. In a USA study, 83% of 175 respondents reported that they considered prescribing errors to be unacceptable.[5] In an Australian study, 190 doctors who were given a 12-item dosage calculation test felt that achieving 91.6% (11 out of 12 correct) was acceptable. However, they scored at a significantly lower level than this, attaining a mean of 72.5%. The authors of the study were concerned that the majority of participants (79%) reported that they had not been tested for this ability previously, a finding which suggests that this skill is assumed.[2]

Wheeler et al[6] found that the majority of tested medical students were unable to correctly determine what mass of a drug was contained in a particular volume of solution.

These authors believe that this skill is overlooked in medical education and recommended that students should be familiar with such arithmetical concepts when they begin prescribing. Burch et al[7] pointed out that in the South African context, academic performance may be a particular problem for students who enter university with a poor educational background. Such students arrive at medical school and are at a particular disadvantage in terms of the literacy and numeracy skills that are needed to extract, interpret and manipulate relevant information for the appropriate administration of medication.

In the present study, we investigated the ability of medical students at the Nelson R Mandela School of Medicine in Durban to calculate drug doses.

Method

Ethical approval (Reference No BE185/09) was obtained from the University's Biomedical Research Ethics Committee. After students entered the third year, they provided written informed consent and received an hour-long introductory lecture before relevant questions were included in their first test (the baseline assessment). They were then tested repeatedly until the end of fourth year. Questions were included in the formal exams and tests that the students wrote. Questions were answered under exam conditions. Because some students failed and wrote supplementary exams, some of the students were not tested the same number of times. During the course of the study, training involved formal lectures and tutorials, as well as assignments with model answers for self-assessment.

There were four dosage calculations in every test. One involved the drip rate, while the other three focused on the required volume of a medicine to be administered when the drug concentration was expressed either as a mass per unit volume, a ratio or as a percentage.

A student was only considered to be competent provided he or she had all four types of calculation correct in a particular test, i.e. attained 100%. An investigation was carried out into how many students began competently after the brief introductory lecture. It was determined how many tests were required to achieve competence for those who were not. The progress of the students was then followed to establish whether or not they had retained the ability to score 100% over time. The percentage of time that they were competent was also computed: the number of tests in which each student scored 100%, i.e. was competent, in relation to the total number of tests written, was then determined.

Although competence was defined as getting all four types of calculations correct at one attempt, each calculation represented a patient in real life with the potential to receive an incorrect dose. Accordingly, the findings for each student were broken down into success, or otherwise, using individual questions. Thus, in effect, the number of "patients" who would have received the wrong dose and had the potential to have been harmed by the students could be investigated. The number of incorrect answers provided by each student was determined in relation to the total number of questions answered throughout the course of the study.

To establish which type of calculation the students found to be the most difficult, the number of times each student made an incorrect calculation as a percentage of the total number of opportunities available to answer that type of question, was determined. Differences were assessed using a paired Student's t-test. A p-value of < 0.05 was considered to be statistically significant.

Demographic factors, such as gender, race, English as a home language and school-leaving score were investigated as predictors of performance using Epi Info™ version 3.5.3. To assess significance, the chi-squared test was used for the categorical data (gender, race and English as a home language), while Student's t-test was used for school-leaving scores. Relative risks were also calculated. A p-value of < 0.05 was considered to be statistically significant.

Result

The majority of the 364 students in the study were women (59%). One hundred and eighty-seven (51%) spoke English as a home language. African students accounted for 50%, Indian students 40% and the remaining 10% were white or of mixed race. Of the 336 (92%) who had written the official South African school-leaving examination before entry to medical school, the average (standard deviation) school-leaving score was 44 (5.6) out of a possible 50 points.

Table I: Student outcomes

Group (the number of students)	Students who were competent at the start	Fraction of time that the students were competent	Overall "patients" receiving the wrong dose	Students retaining competence	Median tests after competence (range)	"Patients" receiving the wrong dose after competence
Group 1 (82)	100%	75%	9%	44%	2 (1-7)	13%
Group 2 (157)	0%	39%	31%	71%	1 (0-4)	20%
Group 3 (125)	0%	0%	51%	N/A	N/A	N/A

N/A: not applicable
Competency equated to all four question or calculation types being correct
Each calculation represented a patient in real life with the potential to receive an incorrect dose
Group 1 was competent at the start; Group 2 became competent; Group 3 was never competent

Of the 364 students, 23% (82) were competent at the beginning, while 66% (239) were able to score 100% at least once by the end of the study. Although this represents an overall improvement, detailed analysis of individual students' progress revealed three distinct groups: those who were competent at the start (82), those who developed competence in a later assessment (157), and those who never achieved competence (125).Thus, approximately one third were never competent, even by the end of their fourth year. Some students failed to retain competence in the first two groups. These results are summarised in Table I.

The 82 students in group 1 were competent 75% of the time because only 36 continued to answer all of the questions correctly in the tests. Of a total of 968 questions ("patients"), group 1 students made 85 mistakes. In other words, despite starting out competent, in a real-life situation they would have calculated the wrong dose for 85 patients (9%).

Although 157 students were not competent to start with, they achieved competence and were competent 39% of the time. Most of them (88%) needed only two or three attempts to become competent. The average number of attempts required was three. Details of the number of attempts required by all 364 students to achieve competence are shown in Figure 1.

In total the157 students made 664 incorrect calculations out of a possible 2 156 ("patients"). Overall, they could have negatively impacted 31% of "patients". However, once they became competent, this figure was reduced to 20% (87 incorrect calculations out of 440).

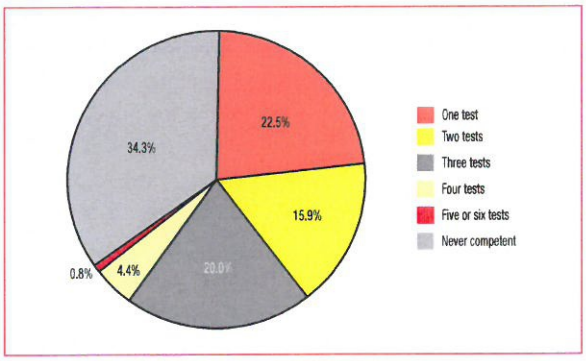

Figure 1: Proportion of attempts required to achieve competence (364 students and 1 258 tests)

Although 125 never became competent, they correctly calculated 943 doses out of a possible 1 908. Conversely, they made 965 errors. Therefore, they would have administered the wrong dose of drug to 51% of their "patients".

Considering all 364 students, they were competent 31% of the time. Overall, they calculated the wrong dose for 34% of "patients".

Even though, as expected, group 1, 2 and 3 performed best in that order, calculations when drug concentrations were expressed as a ratio and percentage presented more of a challenge than the mass per volume and drip rate calculations. These differences were statistically significant (p-value < 0.05) (Table II).

The mean school-leaving score was a predictor of achievement at the beginning (p-value = 0.0001), and to a lesser extent by the time competence was achieved (p-value = 0.0046). However, the differences were very small: 3 and 1 points in the scores respectively. Although there was a relative risk at baseline of 1.2 (1.1-1.4) for not speaking English at home, this effect was lost by the time competence was achieved 1.3 (1-1.7). The relative risks for black Africans were 1.2 (1.1-1.3) and 1.3 (1-1.8), respectively. Gender was not associated with competence at either stage.

Discussion

Our finding that 23% of the students achieved 100% in their baseline assessment was similar to the results of the Australian study in which 28% of participants scored over 90% in a test comprising dosage calculations typical of those required in emergency settings.[2] The Australian participants had the advantage of being qualified doctors so they would already have benefited from clinical experience, whereas our students were given an introductory lecture, which was not offered in the Australian study. Our students had the disadvantage of the stress induced by an examination environment and the fact that the paper cases lacked the contextual setting of the "real world". Another difference was that besides questions involving the concentration of medicine in solution, expressed in different forms (included in both studies), our study also tested the ability to determine drip rates.

Table II: Percentage of time a particular type of question or calculation was answered incorrectly (or, by definition the percentage of time a "patient" would have received the wrong dose)

Group (number of students)	Drug concentration given as a mass per volume	Drug concentration given as a percentage	Drug concentration given as a ratio	Calculation of drip rate
Group 1 (82)	5%	12%	13%	6%
Group 2 (157)	22%	38%	41%	21%
Group 3 (125)	37%	64%	64%	37%
Total (364)	25%	43%	44%	24%

Competency equated to all four question or calculation types being correct
Group 1 was competent at the start; Group 2 became competent; Group 3 was never competent

Training was of value to the extent that of the 282 students who were incompetent at the start, 157 achieved competence and needed on average three tests to achieve this. Although these findings are in broad agreement with those of Wheeler et al,[8] it is very worrying that even after repeated training sessions and assessments over approximately 18 months, 125 students never became competent and calculated the wrong dose of drug in 51% of their attempts.

Overall, students who were competent in the first test performed the best. They were competent 75% of the time, almost twice as often as those who became competent during the course of the study (39% of the time). Although more of the students who became competent during the study retained their competence (71% versus 44% for those who were initially competent), this was not a reliable figure because students in this group had fewer opportunities to remain competent. This was because they had exhausted tests in the early part of the study to gain competence. Because competence was defined as achieving 100%, loss of competence did not reflect the incorrect calculations, i.e. the number of "patients" who received the wrong dose, which, as a result, is a better guide. Overall, students who were initially competent would have administered the wrong dose of drug to only 9% of patients, in comparison to the group who achieved competence, who had the potential to harm 31% of patients. Also, when considering post-competence performance for both groups, the initial achievers would have administered the wrong dose to 13% of patients, approximately half as many as the 20% in the later competent group. Thus, obtaining a good grounding in school of basic arithmetical concepts is particularly important.

Training is perhaps especially critical in our setting as we showed that the relative risks of not speaking English at home and of being a black African were lost by the final opportunity. This suggests that repeated practice and training opportunities allow time to resolve language-related difficulties that might otherwise hamper dosage competence.

Our students performed best when calculations involved mass per volume and drip rate. The finding that ability was influenced by the way in which concentration was expressed confirms that of previous studies in the UK and Australia, where, like ours, candidates fared significantly worse in the ratio and percentage questions.[2,9] These types of calculations were the most problematic, even for our "best" students who were competent at the start of the study. Personal communication with students suggested that they had difficulty conceptualising concentrations that were expressed in this way. For example, when asked to determine the amount of drug in 5 ml of a 10% solution, many students thought this meant that 10% of 5 ml was required.

These calculations also require an additional step, the conversion of the concentration in its ratio or percentage form to one expressed in units of mass per volume. Wheeler et al[9] noted that in other fields of research it was shown that an increase in the number of actions required to complete a process increased the risk of error. Accordingly, they called for the labelling of drugs in solution to be standardised to mass per unit volume.

Smith and Wheeler also stated that until such drug labelling changes are made, the problem will need to be addressed by appropriate undergraduate training.[10] We agree with both their call for labelling changes and for training, and have now made further adjustments to our curriculum to introduce dosage calculation tuition even earlier.

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Conflict of interest

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this paper.

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Paper 2: Assessing medical students' competence in calculating drug doses

Paper 2 page 1

Assessing medical students' competence in calculating drug doses

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Evidence suggests that healthcare professionals are not optimally able to calculate medicine doses and various strategies have been employed to improve these skills. In this study, the performance of third and fourth year medical students was assessed and the success of various educational interventions investigated. Students were given four types of dosing calculations typical of those required in an emergency setting. Full competence (at the 100% level) was defined as correctly answering all four categories of calculation at any one time. Three categories correct meant competence at the 75% level. Interventions comprised an assignment with a model answer for self-assessment in the third year and a small group tutorial in the fourth year. The small groups provided opportunities for peer-assisted learning. A subgroup of 23 students received individual tuition from the lecturer prior to the start of the fourth year. Amongst the 364 eligible students, full competence rose from 23% at the beginning of the third year to 66% by the end of the fourth year. More students succeeded during the fourth than the third year of study. Success of small group tuition was assessed in a sample of 200 students who had formal assessments both before and after the fourth year tuition. Competence at the 75% level improved by 10% in attendees and decreased by 3% in non-attendees, providing evidence of the value of students receiving assistance from more able same-language peers. Good results were achieved with one-on-one tuition where individualised assistance allowed even struggling students to improve.

Introduction

Dosage errors are a cause of morbidity and mortality worldwide. Drug dosage calculations require basic mathematical literacy skills, but competence is inadequate amongst both medical students and qualified, practising doctors.

Dosage calculation in practice

Studies amongst doctors, nurses and paramedics confirm that many healthcare providers are not sufficiently competent in calculating drug doses (Coben, 2010; Conroy et al., 2008; Eastwood, 2009; McMullan, Jones & Lea, 2010; Simpson, Keijzers & Lind, 2009). Medical errors are a worldwide health concern, with dosage administration errors a key finding in the United Kingdom. Consequently, teaching the skills to calculate a dose correctly is an area that needs to be addressed in undergraduate courses (Coben, 2010; National Patient Safety Agency, 2009; Simpson et al., 2009).

Dosage calculation skills have not traditionally been taught to medical students. One explanation for this is that they require proportional reasoning skills; mathematics taught in school is thought to transfer to situations encountered outside school (Stasz, 2001). Consequently, it is assumed that these proportional reasoning skills are acquired at school, although it is not expected that the specific context of dosage calculation will have been encountered there. However, research suggests that mathematical knowledge transfer does not happen readily, partly because of differences between formal knowledge, which may involve mathematical algorithms, and contextual knowledge, which often involves contextual cues as part of the processing (Stasz, 2001).

The cognitivist paradigm versus the sociocultural paradigm

Historically, medical and mathematics teaching have operated within a normative or cognitivist paradigm. Within this paradigm, a skill is considered to be separate from the person acquiring the skill (or measuring the acquisition of the skill) as well as from the context within which it is learnt. It is thus expected that the skill will transfer readily from one context to another (Stasz, 2001). Accordingly, the context within which the skills will be needed is not considered relevant.

The objectification of skills and knowledge in this way has been criticised because it fails to consider the unique ability of the human 'to continually shape and be shaped by their social contexts'

(Roth & Lee, 2007, p. 4). Because the relevance of context is ignored, cultural diversity is not taken into account. It also fails to consider the unique ability of the human to interpret and represent experiences and it ignores or presumes its subjects' interpretation of situations (Cohen & Manion, 1980). Consequently, the role of the relationship between teacher and student is regarded as limited to an opportunity for skills to be passed from the teacher to the student. The control over what is learnt, and how this is done, is with the teacher, the student not seen as needing a voice or requiring an opportunity to be heard. The teacher assumes a student is available to acquire skills if they have been delivered, that the student has then acquired these skills, or will if they make sufficient effort, and has sufficient ability to reinforce learning. The responsibility for the acquisition of the skills, once the teacher has delivered them, is believed to lie with the student.

In contrast, according to the Vygotskyan sociocultural view of learning, skills are learnt naturally within the context of social activity and within a culture using artefacts (such as language or, for dosage calculation, vials, syringes and treatment guidelines) developed within that culture. Accordingly, the skill cannot be understood without reference to the context, namely the development of skill with the socio-historically developed tools involved that mediate thinking, for example the language and equipment relevant to the activity (Rogoff, 1990, p. 35). These contextual factors give the skill its meaning and importance. This assists with motivation to acquire the skill. They provide pragmatic cues which improve performance and assist with retrieval of the skills in future use.

Within the context and culture of social activity there are relationships with other participants. Vygotsky's theory emphasises development as a process of learning to use the intellectual tools provided through social history (Roth & Lee, 2007). Social interaction is expected to foster learning through the guidance provided within relationships with people who are skilled in the use of those intellectual tools (Rogoff, 1990). Accordingly, in a one-on-one relationship a novice will learn from an expert who guides as they participate in a meaningful activity. Key to the learning process within this paradigm is the relationship between novice and guide who engage together in dialogues, which may be tacit or non-verbal. Through these, a guide is able to hear the novice's voice and to be heard and to vary the amount of control needed to ensure the novice moves towards expertise. Within this paradigm, a student is recognised to be more or less available for learning and factors such as anxiety, motivation and distractibility are taken into account. The dialogues allow a guide to be responsive, in other words to provide a balance between support and challenge to keep the student optimally receptive to learning. Dialogues allow the guide to give just the right amount of challenge so that the activity is slightly beyond the learner's competence, within the learner's zone of proximal development. This Vygotskyan concept refers to the range of tasks that can be completed: the lower level of this zone corresponding to the level of skill that the learner can reach independently whilst the higher level refers to the potential skill level that can be completed with the assistance of the expert (Rogoff, 1990, p. 14). Learning is thought to occur through the relationship, which builds a bridge from the mind of the teacher to that of the learner so that the learner can borrow the perspective of the teacher to develop his own skills (Rogoff, 1990, p. 19).

Consequences of the prevailing positivist paradigm to students is that (1) the context particular to dosage calculation has not been provided, hampering retrieval, (2) although proportional reasoning skills may have been acquired at school, these skills may have been taught in the early school years only, and half-forgotten as the students focused on more abstract mathematics, and (3) skills may not have been adequately taught or acquired leaving students incompetent in this area of mathematics, but without a guiding relationship within which to communicate the need for support, possibly leading to anxiety. Aversion towards mathematics is a common phenomenon amongst students in higher education (Taylor & Galligan, 2006) and such anxiety might lead to increased defensiveness, which might prevent them from seeking help at medical school and later from checking answers with colleagues in a clinic situation.

Lack of focus on teaching therapeutics

An approach that may remediate some of the problems of earlier learning within a positivist paradigm is that of problem-based learning (PBL), in which students are presented with a problem that forms the starting point and focus of learning. Students use a problem-solving routine interactively to identify what their learning needs are in order to manage the problem; they then use self-directed learning to meet these needs and then meet to discuss and summarise what they have learnt. A well-designed PBL programme is expected to improve the integration of prior learning with new information, the transfer of skills to a real-life setting and the elaboration of knowledge for better understanding and retention. An established result of PBL research is increased student motivation (Albanese & Mitchell, 1993). There has been widespread adoption of forms of this approach amongst medical schools worldwide since its introduction at the McMaster University School of Medicine in the late 1960s. A problem-based learning medical curriculum has been followed at our (the authors') School of Medicine in KwaZulu-Natal since 2001, with several modifications since 2006 to include an instructor-led basic science module at the beginning of the first year (to provide cognitive scaffolding) and more clinical bedside teaching in the fourth year (Tufts & Higgins-Opitz, 2012).

According to the PBL approach, our students, in small groups and guided by a facilitator, develop common learning goals from a paper case related to a medical theme and report back. Students are expected to reach these goals individually, with support from useful literature, structured learning sessions, tutorials, practicals and clinic or hospital visits.

To some extent, the problem-based learning approach has remedied students' lack of exposure to context because the paper cases provide students with some of the contextual factors of real-life health problems. However, the paper cases focus on diagnosis and less attention is paid to the details of treatment, including the technicalities of prescribing, such as calculating the correct dose. The failure of curricula to emphasise prescribing and 'teaching the skill to treat the patient' is a cause of concern internationally (Hogerzeil et al., 2001). As a therapeutics department, we aimed to improve prescribing competence by offering a programme of therapeutics learning opportunities relevant to the medical themes being discussed, largely in the form of large group sessions and assignments because these fit most readily into complicated timetables.

In light of the inadequate dosage skills amongst doctors and students (Simpson et al., 2009; Wheeler et al., 2004) we (the authors) felt that dosage skills training should be introduced to the medical curriculum. We believed we were best placed to provide the context relevant to dosage calculations and, like Huijser, Kimmins and Galligan (2008), that students 'would learn better if the mathematical skills required for dosing were taught as an integral part of our programme, rather than separated and remediated in a content vacuum' (pp. A-24). Accordingly we set about including dosage calculation training in some of our therapeutic learning opportunities so that students could have opportunities to access prior mathematical skills as well as to determine and remediate missing mathematical skills.

For example, within the endocrine theme, where students are introduced to the body's hormones, one of the students' PBL cases focused on a patient who developed hypercalcaemia (abnormally high levels of calcium in the blood) as a result of overproduction of the hormone involved in controlling the level of calcium in the blood (parathyroid). Our learning session initially focused on which medicines would be used to manage this condition and how these medicines worked. In this case, an appropriate option is the administration, by intravenous infusion, of the medicine pamidronate.

In order to bring in the dosage calculation skills students needed to manage this case, students were provided with dosage information and asked to consider how this drug should be reconstituted from a powder to a solution, what volume of this solution should be added to a litre of normal saline and what drip rate should be set in order for this infusion to be given over 6 hours.

The calculation process

In contrast with medical students, nursing students have historically received dosage calculation skills training. Common practice is to teach, according to rule-based strategy, a formula known as 'the nursing rule' (Hoyles, Noss & Pozzi, 2001, p. 13), explained by nurses as 'what you want over what you've got, times the volume it comes in,' or in its written form:

$$\frac{\text{What you want}}{\text{What you've got}} \times \text{The volume it comes in}$$

We illustrate the use of this formula in solving the following example:

Problem:
A child is to be sedated with 1.5 mg of midazolam. A vial of midazolam has 15 mg in 3 mL. How many millilitres of midazolam are required?

Solution:
What you want = the amount of drug prescribed = 1.5 mg.
What you've got = the amount of drug dissolved in the formulation = 15 mg.

The volume it comes in = 3 mL

So when the formula is applied:

$$\frac{1.5 \text{ mg}}{15 \text{ mg}} \times 3 \text{ mL} = 0.3 \text{ mL}$$

Shortcomings associated with using formulae are recognised. Coben et al. (2010) contrast memorising a formula with developing a competence where,

> when presented in a particular context with a prescription with a specified dose, an ampoule with a particular strength and volume and a choice of syringes with which to draw it up, a student can manipulate these to produce the correct prescribed dose. (p. 4)

A formula may be forgotten when it is needed in practice or the vague terms involved may lead to the inclusion of incorrect values; for example, 'what you've got' may be understood as the concentration rather than the amount of drug and this wrong information would lead to calculation of the wrong dose.

Various educational interventions have been implemented and found to improve dosage skills amongst nursing students. In comparison with traditional lectures, where formulae (such as the nursing rule) were taught, significantly higher sustained learning was reported with methods that built on students' existing mathematical problem-solving skills and focused on avoiding conceptual errors (Gillies, 2004; Koohestani & Baghcheghi, 2010). With this in mind, we avoided the mechanistic use of formulae.

Vergnaud's (1982) model of proportionality includes a multiplicative structure involving direct proportion between two measure spaces. Determination of an appropriate volume of a drug in a solution could be characterised by this structure, the measure spaces being the mass of the drug and the volume of the solution. According to this model, the correct volume of a drug could be obtained either by rule-based, functional or scalar approaches. The first two approaches involve manipulating figures *across* measured spaces, whilst the last (that is the scalar approach) involves working only *within* measure spaces by adopting various strategies. Nurses, although generally taught rule-based

strategies, most commonly adopt scalar strategies in a clinical setting (Hoyles et al., 2001). Scalar approaches to solving proportionality problems are more flexible and generalisable to the workplace, preserving the meaning of the quantities and their relationship by keeping variables separate (Nunes, Schliemann & Carraher, 1993).

In view of these findings, we adopted a scalar approach to solving dosage problems in our large group sessions to help keep students in touch with the meaning of the quantities. We called it the 'two column stepwise method' in which 'whatever was done' to one column (one measure space: mass) 'was done' to the other (the second measure space: volume). In other words the same arithmetical calculation was applied to each measure space.

Corresponding with the unitary method (one of the scalar strategies described by Vergnaud (1982), the initial step is to reduce the quantity in the first space to unity (one). This is illustrated in Figure 1 using the problem and solution below.

Problem:
A child is to be sedated with 1.5 mg of midazolam. A vial of midazolam has 15 mg in 3 mL. How many millilitres of midazolam are required?

Solution:
In order to get from 15 mg to 1.5 mg the first 'step' is to get to 1 mg by dividing the number by itself (in this case 15). The same divisor is then applied to the second column (volume). Next, the resultant numbers in both columns are multiplied by 1.5.

After this, students are required to be pragmatic and to check, in a different way, that the answer 'makes sense'. This means appraising whether the result obtained is feasible. For example, in the above example a different scalar approach can be used to see if the answer 'looks' sensible: 1.5 mg is a tenth of 15 mg, so a tenth of 3 mL is needed and a tenth of 3 mL equals 0.3 mL.

The 'two column stepwise method', followed by the pragmatic check, was used in all large group sessions, report backs and model answers.

The sociocultural perspective and best teaching practices

In our efforts to design appropriate and effective dosage calculation training we were cognisant of the fact that the students and medical school operate within the context of a newly democratic post-conflict society in which continuing poverty and inequality exist. Within this society there are two needs affecting curriculum decisions: one is the focus on equity and social justice to redress historical inequality and the other is the drive to develop skills for further learning and participation in a globalised and increasingly technological workplace (Vithal, 2012). Teaching within the sociocultural paradigm, which requires students to have a voice and to participate in the learning process whilst still being guided by the societal need for competent prescribers, would meet these needs.

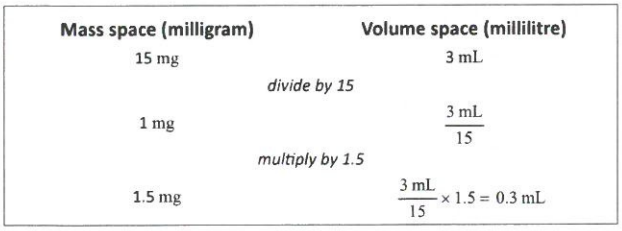

FIGURE 1: Illustration of the 'two column stepwise method.'

Accordingly, we aimed to improve learning from the sociocultural perspective, within the constraints of the teaching interactions we could readily provide for students, namely the large group session and assignment for self-assessment. One of the goals relevant to large group sessions would be to provide meaningful tasks that closely resemble those that must be undertaken in the workplace as a focus for joint attention. Although resource and safety restraints precluded the use of real tasks, we developed paper dosage calculation problems of patients receiving drug treatment for conditions relevant to the current theme, using formulations and dosage regimens that would be encountered in practice in order to preserve sufficient meaning for learning to occur and be transferable to a clinic setting, as advocated by Coben (2010, p. 10).

We also took guidance from the seven hallmarks of good practice in undergraduate education, as described by Chickering and Gamson (1987). These were developed from 50 years of student and teacher experience and research and are widely regarded as a gold standard for measuring the quality of undergraduate education. These guidelines include encouraging student-faculty contact (improving student-teacher communication would be an important part of this contact), developing cooperation and reciprocity amongst students, participating in active learning, providing prompt feedback, communicating high expectations, respecting diversity and emphasising the necessity of dedicating time to the acquisition of a skill ('time on task'). These guidelines fit well with the sociocultural paradigm because the seven principles would be expected to occur within the social dialogues between a learner and a teacher or a more competent learner working together on a meaningful activity.

Our teaching

After we included dosage calculation training in our large group sessions and assignments, with a particular focus on real-life contextual examples, we assessed student competence as the years progressed. This allowed us to evaluate the impact of 'time on task'. In an effort to improve student dosage competence further we aimed to enrich the interaction between learners and experts (whether teachers or more capable students) in our interventions. We gave individual students one-on-one tuition (strengthening student-teacher

contact) and offered a tutorial that allowed for peer-assisted learning (developing cooperation and reciprocity amongst students).

Objectives and research questions

Our teaching provided the opportunity to examine the impact of three of Chickering and Gamson's principles (1987, p. 3) and consequently our research questions were: What is the effect of (1) time on task, (2) peer-assisted learning and (3) closer student-teacher contact on dosage calculation competence amongst medical students?

Research design

Materials and setting

We examined the responses of medical students at our School of Medicine in KwaZulu-Natal to dosage calculation problems included in examinations during their third and fourth years. We also examined case notes, written responses to paper problems and interview transcripts collected during the individual tuition of 23 of these students who were selected from those who were not able to dose competently by the end of their third year.

Most of the students started medical school immediately after leaving school and the median age of our group was 21 years with a range of 18–34, as a few students already had other degrees. There is considerable diversity in terms of both culture and educational background, with students drawn from homes with eleven different languages other than English. The majority of students come from government schools, some of which were historically disadvantaged in terms of resources and access to skilled teaching. Other students come from advantaged privately funded schools, both in South Africa and neighbouring African countries.

Design and procedure

Medical students at our School of Medicine were exposed to various different dosage calculation training methods during their third and fourth years of study. Paper problems involving formulations of medicines and regimens included in the South African Standard Treatment Guidelines (Department of Health, 2008) were used as training and assessment material. The calculations were of four different types, namely the determination of a drip rate and three calculations where the concentration of drug was expressed in three different ways: in units of mass per volume (e.g. midazolam labeled as 5 mg/mL), as a ratio (e.g. adrenaline 1:1000) and as a percentage (e.g. 1% lignocaine).

Every assessment comprised four questions, one of each type. These were randomly selected from a bank of appropriate questions. Students were deemed competent at the 100% level if they got all four calculations correct at any one time. At least three of the four questions correct meant they were competent at least at the 75% level.

After a baseline test at the beginning of third year, students were assessed repeatedly and the cumulative number of students attaining competence by their final assessment in their third and fourth year was measured. In order to investigate the effect of 'time on task' advocated by Chickering and Gamson (1987), competence acquired in the third year was compared with that achieved in the fourth year.

In the third year, students were given an hour-long introductory lecture and an assignment, followed a week later by a report-back session and a model answer for self-assessment. In fourth year, in an effort to improve 'peer contact' as advocated by Chickering and Gamson (1987, p. 3), they were offered a further lecture followed by a tutorial in which they worked together through examples. It was hoped that this peer-assisted teaching strategy would help to overcome language barriers, as students would be able to seek assistance from more able same-language peers. A sample of 200 of these students were given formal assessments both before and after the extra tuition. The change in calculation competence was compared between those who attended and those who did not.

In an attempt to test the value of increasing 'contact between students and faculty' (Chickering & Gamson, 1987, p. 3), 23 students were offered individual tuition prior to the start of the fourth year. After giving written consent, each was asked to work through dosage calculations that they had previously answered incorrectly. If they faltered, the researcher would provide just sufficient information or explanation to enable the student to continue and would make a note of the difficulty experienced by the student. The interview transcripts, written calculations and case notes were analysed to determine common key problems experienced by the students. The influence of one-on-one teaching on student competence was assessed retrospectively by comparing their results for assessments immediately before and after this tuition.

There were two subgroups in this group of 23 students. The first (N = 13) was sampled from those who in previous tests had omitted questions or made errors where the student's reasoning could not be followed. The sample was stratified across the range of student ability. The second subgroup (N = 10) was a convenience sample from the poorest performing students. There were 38 such students all of whom were invited but only ten chose to attend. Details of the training offered to the different groups of students are provided in Table 1.

TABLE 1: Training offered.

Group	Whole group time on task (N = 364)	Tutorial peer-assisted learning (N = 200)	One-on-one tuition faculty-assisted learning (N = 23)
Third year	Lecture Assignment and model answer	Lecture Assignment and model answer	Lecture Assignment and model answer
Fourth year	Revision lecture and tutorial	Revision lecture and tutorial	One-on-one faculty teaching Revision lecture and tutorial

N = number of students assessed in each group.

Statistical analysis

Epi-Info version 3.5.3, a public domain statistical software package for epidemiology (Centre for Disease Control and Prevention, 2011), was used to perform Chi-squared tests and risk ratio calculations to investigate demographic factors, including race and English as a home language, as predictors of performance, as well as to compare change in calculation competence between group tutorial attendees with those who did not attend these sessions. Statistical significance was set at a level of 5% or less (i.e. $p < 0.05$).

QSR NVivo 8, a software package for qualitative data analysis (QSR International, 2008), was used to analyse the material related to the students given individual teaching sessions to determine the key problems they experienced.

Reliability

In order to ensure the reliability of results, our questions were based on a tested instrument to assess dosage competence. This instrument comprised questions from an Australian study (Simpson et al., 2009). We modified this instrument slightly where necessary to reflect dosage formulations and regimens used in South Africa.

Validity

In order to ensure that our measurement of student ability would reflect their ability as future doctors to dose their patients appropriately, we aligned our teaching and assessment materials as closely as possible with situations that will be encountered when prescribing and administering a drug. We used the prevailing prescribing regimens and formulations recommended by the texts that guide prescribing in South Africa, the South African Standard Treatment Guidelines (Department of Health, 2008) and South African Medicines Formulary (University of Cape Town Division of Clinical Pharmacology, 2010). Students were provided with pictures and explanations of materials and equipment peculiar to the task of dosing drugs, such as vials, ampoules, powders requiring reconstitution, administration sets and infusion solution bags. The assessment questions selected were typical of those encountered in an authentic emergency setting.

Ethical considerations

Ethical approval (reference number BE185/09) for this mixed-methods study was obtained from the University's Biomedical Research Ethics Committee. After being given written information, each participant gave their written informed consent to the written publication in a research journal of the overall findings from their data.

Findings

Of the 364 students eligible for the study, 82 were found to be competent at the 100% level at the beginning of their third year. Of the 282 remaining, 58 (20.6%) were competent by the end of third year. By their last test in fourth year, 99 of the remaining 224 (44.2%) had attained competence. Thus, more students became fully competent during the fourth than during the third year. Likewise in the third and fourth year respectively, 29.6% and 54.9% of students became newly competent at the 75% level (Table 2). At each screening stage, students who did not achieve full competence but who attained competence at the 75% level were most commonly prevented from achieving full success by a mistake with a calculation involving concentrations expressed as a ratio or percentage (each between 31% and 43% of the time). Mistakes with mass per volume and drip rate questions which prevented full competence were made in between 6% and 22% of cases. Of the 364 students, 51% were English speaking whilst the rest spoke an African language at home. The average age was 21 years with an age range of 18–34 years. Over half (59%) were female students. Although race and home language were predictors of performance at baseline, both associations had been lost by the final assessment. Neither age nor gender was associated with competence either at the beginning or the end of the study.

In the subgroup of 200 students who had formal assessments both before and after the fourth year group tutorial, 83 were attendees and 117 non-attendees. Attendees performed better overall before tuition, 30% and 55% of them scoring 100% competency and 75% competency respectively. Equivalent figures for non-attendees were 21% and 53%. Attendance made no difference to students' ability to achieve 100% (0% and 3% change for attendees and non-attendees respectively (Table 3). However, attendance had a significant influence on

TABLE 2: Number and percentage of students competent over time ($N = 364$).

Screening stage	Number competent at		Number not yet competent at		Percentage competent at		Percentage newly competent at	
	100% level	75% level	100% level	75% level	100% level	75% level	100% level	75% level
Start of third year	82	172	282	192	23%	47%	-	-
End of third year	140	232	224	132	38%	64%	21%	30%
End of fourth year	239	305	125	59	66%	84%	44%	55%

N = number of students.

TABLE 3: Percentage of students competent before and after peer-teaching intervention ($N = 200$).

Screening stage	Attendees ($N = 83$)		Non-attendees ($N = 117$)	
	100% competence	75% competence	100% competence	75% competence
Beginning of third year baseline	14%	34%	11%	43%
End of third year before intervention	30%	55%	21%	53%
End of fourth year after intervention	30%	65%	24%	50%

N = number of students.

the numbers of students achieving 75% competency (10% and -3% changes for attendees and non-attendees respectively, $p < 0.05$). There was no statistical difference in improvement for any of the four different types of question between the attendees and non-attendees.

Regarding the one-on-one teaching, in the group with the range of abilities ($N = 13$), three students did not attend the final assessment. The remaining 10 all finally achieved 100% – four having started at 25%, four at 50% and two at 0% (Table 4).

In the subgroup comprising the very weakest students ($N = 10$), three students did not complete the final assessment. There was an improvement amongst the remaining seven, most of whom started with 0%. The marks of three improved from 0 to 50% and one each from 0 to 25%, 0 to 75%, 0 to 100% and 25 to 50% (Table 5).

During the interviews, it was apparent that students most frequently had difficulties with the concentration of a solution expressed as a ratio or percentage. The next most commonly encountered problem was unit conversion, for example converting from milligrams to grams or micrograms to milligrams.

The group comprising very poor students had the additional difficulty that, despite our efforts, they still did not understand that the concentration of a solution is actually giving information about the quantity or mass of a substance relative to the volume, in other words two variables. This group was also overly reliant on calculators. They lacked an ability to simplify numbers or see patterns and had no insight into an unrealistic number generated by the calculator.

TABLE 4: Dosage results for stratified sample of students given one-on-one teaching.

Score achieved	0%	25%	50%	75%	100%
Beginning of third year ($N = 13$)	6	4	3	0	0
End of third year ($N = 13$) before intervention	4	4	4	1	0
End of fourth year ($N = 10$) after intervention	0	0	0	0	10

N = number of students.

TABLE 5: Dosage results for sample of very weak students ($N = 10$; 3 not included in final assessment).

Score achieved	0%	25%	50%	75%	100%
Beginning of third year ($N = 10$)	6	3	1	0	0
End of third year ($N = 10$) before intervention	6	3	1	0	0
End of fourth year ($N = 7$) after intervention	0	1	4	1	1

N = number of students.

Discussion

More students became competent, at both the 100% and 75% level, during the fourth than during the third year of study. This could be due, in part, to the fact that by fourth year students had had more calculation practice. There is some evidence of this in that a small number of students improved to the 100% level even though they did not attend the group tuition. In other words, repeated learning and assessment over two years allowed students to benefit from spending 'time on task', consistent with the findings of Chickering and Gamson (1987, p. 3). Celebi, Weyrich, Kirchoff and Lammerding-Koppel (2009) found an improvement in prescribing skills even amongst a control group of students and attributed this to a training effect as students gained practice with the assessment method. Amongst nurses, inclusion over three years in drug calculation learning opportunities, which gradually increased in difficulty, and repeated assessment were found to be successful strategies (Elliott & Joyce, 2005). For students achieving at the 75% level of competence but failing to attain full competence, calculations involving concentrations expressed as a ratio or percentage presented the most difficulty. Such calculations have also been found to present the greatest difficulty in other studies (Simpson et al., 2009; Wheeler et al., 2004).

There was significant improvement in those students who attended the group tuition. Besides affording students dedicated time to focus on calculations away from competing priorities, the small groups provided more intimacy as there were fewer students present than in lectures. This gave students the opportunity to learn from more competent peers who may have guided them through difficult steps and clarified areas of misunderstanding. This finding is in line with the advantage of peer-assisted learning proposed by Chickering and Gamson (1987). In a group of nursing students, guidance from mentors and informal opportunities to engage with slightly more competent peers were also found to be helpful (Penman & White, 2006). Help and support from peers also afforded an opportunity for theorisation of learning in a more accessible language as, because there are 11 official languages and limited personnel within these language groups with appropriate teaching skills, teaching and assessments are entirely conducted in English. It is interesting to note that, by the end of our study, not speaking English at home had been lost as a risk factor for poor calculation competence.

One-on-one teaching markedly improved competence. All randomly selected students achieved 100% and even in the group selected from the poorest students, most improved. Our success with individual tuition is consistent with Vygotsky's theory of learning: when the informal, disorganised concepts of the learner meet with the formal, methodical reasoning of the teacher this allows for co-regulation between the teacher and the student (Fogel, 1993). This state of inter-subjectivity between the student and the teacher enables the teacher to guide the student forward toward a better understanding of a situation (Kolikant & Broza, 2011).

Students who participated in the one-on-one interventions also had good attendance at the group tuition, so their results are a reflection of both group and individual tuition. It may be that the competence they developed during the individual tuition motivated them to attend the group tuition.

During the one-on-one interviews, it was apparent that students' most common problems related to selecting the

appropriate units to express a concentration given as a ratio or percentage. This was in line with findings from the written assessment, where such questions were more problematic for students achieving at the 75% level of competence but failing to attain full competence. In the randomly selected group of interview students, once this was clarified they were able to develop competence and master the calculations. The next most common problem, namely that with unit conversion, was also improved with individual teaching.

The group comprised of the very weakest students had additional conceptual problems that benefitted in particular from the one-on-one tuition. This was consistent with Jackson and De Carlo (2011), who found that nursing students with conceptual deficiencies required more rigorous remediation. Similarly, Kolikant and Broza (2011) contend that low-achieving students need appropriate interventions to improve their conceptual understanding.

The very weak group struggled with the concept of the strength of a solution and the idea that a ratio or percentage can describe the relationship between the amount of drug in a solution and the volume of that solution. This suggests that they had difficulty handling intensive quantities, which are measured by a relation between two variables. Concentration (an intensive quantity) is measured in terms of units of mass per units of volume. Reasoning about intensive quantities has been shown to be difficult for school children who lack opportunities in school to develop this understanding (Nunes, Desli & Bell, 2003).

Although one-on-one teaching may seem like a luxury in a world where cost-cutting exercises make it a rarity, it does have benefits beyond the obvious; Huijser et al. (2008) noted that 'meanings negotiated during one-on-one consultations are not a one-way street, but rather part of a mutual learning experience during which valuable insight is gained'. They noted that individual teaching provides the opportunity for teacher responsiveness not only to the learner receiving the individual tuition but, by allowing misconceptions to be identified, to the group as a whole. Likewise, once our individual teaching had revealed that understanding related to intensive quantities could not be taken for granted, we changed our overall practice. We now include visual representations of particles in solution in our large group learning. We also make the analogy that when a large cup of sweet tea is poured into smaller cups it maintains the same sweetness (concentration), although the amount of sugar and volume of liquid in each cup is less.

Once students are reminded of their understanding of intensive quantities in this way, the idea that drug concentrations describe the relationship between two quantities (or Vergnaud's two measure spaces) is introduced. The teacher now describes a hypothetical 1% solution, asking students to imagine 1 g of powdered active ingredient dissolved in 100 mL of water and then poured into each of one hundred 1 mL ampoules. Attention is drawn to the fact that the concentration has not changed; it remains 1%.

The very weak students were also overly reliant on calculators. This may have contributed to their lack of insight into an unrealistic result generated by a calculator. McMullan et al. (2010) found that young nurses who had relied on calculators since school had a false sense of security, resulting in more conceptual errors. Gillies (2004) has also expressed concern that unquestioning learning of a formula as well as over-reliance on a calculator could prevent students from monitoring their calculations thoughtfully causing them to blindly accept results, abandoning common sense and resulting in the acceptance of clearly unreasonable answers (Gillies, 2004).

Conclusion

Our study found that student competence improved with repeated exposure and training using the scalar 'two column stepwise method'. Group tuition helped struggling students to improve further, confirming the value of providing opportunities for learners to focus jointly on authentic paper problems with teachers or more capable peers. Although time consuming, one-on-one tuition achieved good results with individualised assistance, allowing even the very poorest students ultimately to improve. The insight gained from these interactions allowed us to provide responsive subsequent learning interactions. Accordingly we modified our programme to incorporate interventions focused on the understanding of intensive quantities.

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Competing interests

We declare that we have no financial or personal relationships that may have inappropriately influenced us in writing this article.

Authors' contributions

C.H. and J.B. (both from University of KwaZulu-Natal) were responsible for experimental and project design. C.H. performed the data collection and statistical analysis. C.H. and J.B. collaborated in writing the manuscript.

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CHAPTER 5 BROADENING DOSAGE TUITION WITH WORKPLACE CONTEXTUAL INFORMATION

Research question 3

How does broadening a drug dosage practice task to include more workplace contextual information change success?

This chapter describes the study findings that answer the third research question. At the end of the chapter is a results summary in tabular form, followed by Paper 3 where the findings of the randomised controlled trial are presented.

5.1 Randomised controlled trial

The results of the study examining the effects of aligning a dosage calculation assessment with the practice of dosing a drug as it would be encountered in the workplace are provided in Table 5.1. For each group of students, the percentage who managed the tasks they were set successfully is provided. Overall, students performed significantly better when provided with numerical information than when having to retrieve it from guidelines. Using dosage equipment to draw up the dose which had been calculated resulted in improved success for students using information embedded in guidelines (RR=2.5 95% CI 1.1-6.1), but did not result in an overall improvement or an improvement for students who were given numerical information in their paper problem.

Table 5.1 Percentage of students (n = 239) dosing successfully

<table>
<tr><td></td><td></td><td colspan="2">Numerical information provided
(information not embedded)
44% success (n = 120)</td><td colspan="2">Numerical information from guidelines
(information embedded)
18% success (n = 119)</td></tr>
<tr><td></td><td rowspan="6">χ^2 = 2.3383; p = 0.126</td><td colspan="4">χ^2= 19.6582; p = 0.0000092603</td></tr>
<tr><td>No Equipment provided 26% success (n = 121)</td><td rowspan="4">Group 1 vs. 3: RR 1.0737 (95% CI 0.7180-1.6056)</td><td>Group 1: Given numerical information asked to write volume needed (n = 61).
43% success</td><td>Group 2: Given formulary excerpt asked to write volume needed (n = 60).
10% success</td><td rowspan="4">Group 4 vs. 2: RR 2.5424 (95% CI 1.0588-6.1049).</td></tr>
<tr><td></td><td colspan="2">Group 1 vs. 2: RR 4.2623 (95%CI 1.8904-9.6103)</td></tr>
<tr><td>Equipment provided 36% success (n = 118)</td><td>Group 3: As for Group 1+ given syringe and labelled formulation + asked to draw up dose (n = 59).
46% success</td><td>Group 4: As for Group 2 + given syringe and labelled formulation + asked to draw up dose (n = 59).
25% success</td></tr>
<tr><td></td><td colspan="2">Group 3 vs. 4: RR 1.8000 (95%CI 1.0724-3.0211)</td></tr>
<tr><td colspan="6">Overall success 31%</td></tr>
</table>

5.2 Error analysis

Unexpectedly, many students who were asked to prepare the required volume made measurement errors, drawing up doses that were different from those they calculated. For the students asked to prepare doses (n = 118), 42 students (36%) both calculated and drew up doses correctly. An additional thirty three students (28%) could be said to demonstrate measurement success but not dosage calculation ability, drawing up the same dose they had incorrectly calculated. Twenty six students (22%) could not prepare the calculated volume even though it was small enough to be drawn up in the syringe. However, an analysis of student errors showed that dosage equipment 'guided' students, causing them to respond

with less implausible quantities (17% of students with equipment compared with 44% of students without) and incorrect measurement units (20% of students with equipment and 40% of those without). Details relating to this research are described in Paper 3, *Examining the role of contextual factors in dosage calculation.*

In addition to the results included in Paper 3, analysis was also conducted to find out how successful students were at retrieving numerical information from guidelines or formulation labels. They would have had to find both the mg/kg dose and then also the formulation information before they could even start to use their proportional reasoning skills. Table 5.2 summarises student success with each task individually and then (in the last column) those who made it successfully through both tasks to start calculating with all the information.

Table 5.2 Student success when retrieving numerical information

(from guidelines of equipment)

Group	Number (%) successfully finding mg/kg dose	Number (%) successfully finding concentration of formulation	Number (%) retrieving successfully overall
Guidelines only (n = 60)	45 (75%)	23 (38%)	19 (32%)
Guidelines + formulation label (n = 59)	44 (75%)	37 (63%)	25 (42%)
Formulation label only (n = 59)	Information given	34 (58%)	34 (58%)

For groups that had to retrieve embedded numerical information, only 32%, 42% and 58% of students were able to find the information they needed (the formulation concentration and the mg/kg dose that would be used with the patient's mass to calculate. Consequently, only these students would be in a position to work out the volume correctly. This is without taking into consideration retrieving and making sense of the information that this is a daily dose and must be split into three divided doses. The students retrieving from only guidelines struggled most with finding the formulation information. Those in the groups with the labelled bottle were significantly better at finding the formulation information.

Extraction of embedded dosage information from guidelines and the provision of dosage equipment information as visual cues are required during training and assessment to prepare medical students for work.

5.3 Limitations

Because students had not been expected to struggle to draw up a dose in a syringe this skill had not been taught. It would have been useful to have a follow up study with maybe the same drug and a patent with a different weight after students had received syringe measuring tuition but not yet received feedback about the question. It would have been useful to have had several such cases and to examine differences between them.

Table 5.3 Research summary

Research question: How does broadening a drug dosage practice task to include more workplace **contextual** information change success?

Research type	Task undertaken by the students or researchers	Sample academic level (n)	Contribution to the understanding/resolution of the problem
Quantitative Randomised controlled trial	Students randomised to 4 groups Group 1 ($n = 61$) Given numerical information asked to write volume needed Group 2 ($n = 60$) Given formulary excerpt asked to write volume needed Group 3 ($n = 59$) As for Group 1+ given syringe and labelled formulation + asked to draw up dose Group 4 ($n = 59$) As for Group 2+ given syringe and labelled formulation + asked to draw up dose	$n = 239$ 1st year students (Cycle II)	• Success for Group 1 was 43%, Group 2 was 10%, Group 3 was 46%, Group 4 was 25%*** • Task was significantly easier when numerical information was provided • ($n = 120$) *vs.* extracting from guidelines ($n = 119$) (44% *vs.*18% $p < 0.0001$)*** • There was no significant difference between groups using dosing equipment to draw up doses ($n = 118$) and those just calculating the volume ($n = 121$) (36% *vs.* 26%; $p > 0.05$)*** • Equipment helped students retrieving information from guidelines (25% *vs.* 10%; RR 2.5; 95% CI 1.1-6.1)***
Qualitative Thematic analysis	Researchers analysed responses: focussed on errors and compared the proportion of different error types for different groups Researchers also determined student success at retrieval of mg/kg dose and concentration of the formula	$n = 239$ 1st year students (Cycle II)	• Equipment guided students' use of **appropriate units** *** Incorrect units were used by 20% and 40% of students with and without equipment respectively***. • Equipment helped students avoid **unrealistic quantities***** Students with equipment calculated less unrealistic quantities than those who had no equipment 17% *vs.* 44%)*** • Regarding **retrieval difficulties**, finding the **formulation concentration** was more difficult for all groups required to do so, compared with finding the **mg/kg dose.** • Formulation concentration retrieval was hardest for guidelines only group (38% *vs.* 58% (retrieval formulation label) and 63% retrieval (both) • mg/kg dosage information retrieval 75% of students asked to do so, managed to retrieve from guidelines

*** Included in Paper 3

Paper 3 Examining the role of contextual factors in dosage calculations

EXAMINING THE ROLE OF CONTEXTUAL FACTORS IN DOSAGE CALCULATION

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Keywords

drug dosage calculations; contextual factors; health literacy; medical education; effect of home language; embedded numerical information

Abstract

Medical students generally learn to calculate drug doses using paper problems containing numerical information. In contrast, once qualified, they have to extract the relevant information from treatment guidelines and use equipment, such as syringes, to dose patients. We compared students' success using the different approaches. After receiving relevant training, 239 consenting first year students were randomized into four groups. Groups 1 and 2 had to calculate a dose, while Groups 3 and 4 had to both calculate and then prepare a dose using a formulation and syringe. We gave Groups 1 and 3 numerical dosage information. Groups 2 and 4 had to extract this information from guidelines. We determined error frequencies and associations using Epi-Info (version 7.2.2.6). Groups 1 and 3 performed best with 43% and 46% success respectively. This was significantly better ($p < .001$) than Groups 2 and 4 who had to extract embedded information, 10% and 25% success respectively. Equipment improved success between Groups 2 and 4, but not significantly so. Non-English speaking students were three times more likely to answer incorrectly and overall were only successful 16% of the time. Incorrect units were used by 20% and 41% of students with and without equipment respectively. Students without equipment calculated more unrealistic quantities than those who had equipment (33% versus 11%). Medical student training and assessment should include both extraction of embedded dosage information from guidelines and use of the equipment used in dosing.

Background

The ability to calculate and deliver the correct dose is of pivotal importance to the use of medicines. Although health professionals are expected to be proficient in this regard, studies have shown that unfortunately, even for qualified doctors, this is not always the case (Coben et al., 2008; Davis et al., 2013; Botha et al., 2006; Simpson et al., 2009).

We have previously investigated drug dosage calculation competence in our South African medical students. Training, including a scalar problem-solving approach which allows students to preserve the meaning of the situation and the quantities they are manipulating, improved success. However, the paper problems still generated some unrealistic responses, for example quantities which should have been recognised as too large to be injected. (Harries & Botha, 2013a, 2013b). Similarly, other medical students have been found to accept incorrect answers because they failed to critically analyse the dosage volumes calculated (Taylor, 2019). Likewise, nursing students were found not to thoughtfully monitor calculations 'abandoning common sense and resulting in the acceptance of clearly unreasonable answers' (Gillies, 2004).

However, Wright (2007, 2010) found that, although nurses did not perform well in paper dosage calculations in the classroom, there was no evidence that they calculated incorrectly in the hospital setting. In fact practicing nurses demonstrated competence when observed dosing drugs in the workplace, seldom using a formula when calculating doses in the ward instead mainly choosing a scalar approach, learned on the job, so keeping connected to the meaning of the quantities they manipulated (Hoyles et al., 2001).

Some authors have expressed concern that skills learned in a classroom may be difficult to transfer to the workplace (Stasz, 2001). Workplace mathematics looks different to school classroom mathematics, it is embedded in artefacts and routines, is idiosyncratic and can often only be understood in context (Hodgen, 2013). The sociocultural approach of Vygotsky is also pertinent: it recognises that learning occurs within a context involving specific tools or artefacts, specific ways tasks are processed and specific social interactions which form part of, and shape, the learning to the extent that they become part of the learner's mental processing. For example, artefacts used to perform workplace tasks are eventually represented as mental tools that form part of the worker's thinking (Vygotsky, 1978a).

This recognition of 'workplace mathematics' has led to the study of how workplace and classroom contexts affect learning and using mathematics (Carpenter et al., 2004). According to the sociocultural perspective, learning occurs within a context comprised of interactive systems or social settings that are larger than the behaviour or cognitive processes of a single person. This social setting is an integral part of the cognitive activity, not simply an inert backdrop. The context shapes the learner, whose learning then feeds into the context reshaping it so it is constantly changed in response to those who are learning there. Consequently, learning opportunities in the workplace allow for the development of future competence in this setting. Carraher and Schliemann (2002) argue that the participation in an authentic task in workplace learning, where the success of the task matters, makes the task meaningful and provides the motivation which drives the development of competence.

This led us to examine workplace learning research for health care workers, focusing on how workplace artefacts are intrinsic to situated learning. Artefacts must be considered taking into consideration the context from which they are drawn. For example, one study found that nurses' methods for evaluating a child's average blood pressure would be judged incorrect according to strict mathematical criteria, but were sensible for making sense of the child's blood pressure readings. Their image of what an average meant was tied up with blood pressure charts, and could not be readily understood as appropriate without these in mind (Noss et al., 1999). In another study, student ability to dose correctly was improved after using an interactive representation of a syringe to visualise the reality of their calculation (Weeks, 2001), while a crossover study of two groups of nurses, one with and one without equipment, found that the group who had exposure to the equipment first did better in the ordinary written calculations (Wilson, 2003).

While dosage calculation skills taught on the ward keep learning closest to practice (retaining the authenticity and contextual factors), relying on workplace learning alone has several limitations. These include lack of exposure to the full range of complexity of patients, drug formulations, their different concentrations and the mathematical transformations required (Coben, 2010a). Carraher and Schliemann (2002) also recognise that variety may be absent in some workplace experience. A further limitation mentioned by Coben (2010a) is that learning depends on the dosing ability while explanations from an expert guide may sometimes be lacking. She believes that mathematics situated in a vocational practice should be taught and assessed, both in classroom simulations, providing safe and comprehensive exposure to the range of mathematical problems students could encounter, as well as directly in practice.

We suspect that workplace mathematics studies often focus on people whose skills have been sufficient to keep them successfully at work. If mathematical competence is pivotal to remaining in the workplace, then those who do not develop competence are automatically excluded. They leave the workplace and so are not available as participants. Workplace studies also fail to consider what factors have supported or hindered the development of competence. For example, the role of possible guides remains invisible, which could lead to the assumption that all participants became successful independently through immersion in the authentic setting where mathematical reasoning was essential. Such differences have to be considered when comparing the survival of the fittest learning findings of some workplace mathematics research with classroom learning strategies for teaching dosage calculations to medical students, where the goal is for all students to develop workplace competence. A willing competent guide in either workplace learning or in a classroom setting, who could keep challenges within the zone of proximal development (a level between skills already mastered and those which they could perform with the assistance of a guide while participating in an authentic task), would allow students, who might be independently unsuccessful, to build competence (Vygotsky, 1978b).

Stasz (2001) has stressed the importance of considering workplace contextual factors during education and training and of applying the knowledge and skills being learned. She cautions though that, while applied or situated learning is widely valued, the importing of vocational examples into the classroom is 'fraught with conceptual and practical problems that await further research and development'. Such problems include contextual factors being too detailed for the level of learner whose main learning goal is mathematical reasoning.

Our response to situated learning research

While financial and logistic considerations restricted us to large group learning sessions and paper problems, it was possible to include tools connected to drug dosing in the ward. We adapted our paper problems to include workplace artefacts so that they more accurately reflected the task of working out a dose for a patient in the ward.

Numerical information embedded in guidelines

First, instead of providing numerical information in a short vignette, as was done in our paper problems, students would be required to look up dosing information in written guidelines. In our setting this is most commonly the South African Medicines Formulary (University of Cape Town Division of Clinical Pharmacology, 2016) (SAMF) or the South African Standard Treatment Guidelines (Republic of South Africa. Essential Drugs Programme, 2018). These guidelines are textually dense and available only in English, the language of instruction but not the home language for many of our students. In the SAMF, for example, the monograph describing the drug must be located and then navigated to find the sections 'Dosage information' and 'Preparations'. The appropriate amount of medicine for a particular patient must be retrieved. This might be stated as a per kilogram dose which must be multiplied by the patient's weight. Then a suitable available formulation must be selected. For liquid dosage forms, the concentration of the formulation must be found and students must use proportional reasoning to determine the volume of solution containing the required amount of medicine.

Expecting that guidelines would present difficulties for students, particularly those with a home language that is not English, we included guideline navigation in training and assignments, feedback sessions and written model

answers. Many of our students are not English speaking and English as a home language has predicted success in our previous studies of dosage calculation (Harries & Botha, 2013a, 2013b). Mathematics teaching and learning research in South Africa identifies language as the major predictor of success in mathematics learning and assessment (Setati et al., 2009). If students with a home language other than English also have a lower socioeconomic status, this may confound a difference in success seen between students with different home languages. Accordingly, we used attendance at fee-paying or non-fee-paying schools as a proxy measure of student family socioeconomic status, which strongly predicts school academic success (Gustafsson et al., 2016).

Provision of container and measuring devices

Secondly, where a medicine formulation is a solution it is contained in a vial or bottle and dosing involves withdrawing a volume of liquid using a measuring device such as a medicine measure, dropper or syringe. Encountering the real-life capacity limits of a bottle containing a solution, and a syringe with its measurement gradations, as occurs in the workplace, should allow students to evaluate whether the dose they calculated could be measured using the available equipment. If not, there would be a mismatch between their understanding of the quantity calculated and the available evidence. Swansson and Williams (2014) make the point that 'the dialectical opposition and synthesis of the systemic abstract with the concrete is what makes the difference in making mathematics scientific'. He shows how the strategy of setting up a contradiction not fitting students' current understanding of a concept can be used in teaching in order to aid concept development. In our study, if the dose could not be drawn up with the artefacts provided this could provide the impetus to cause students to pause and re-evaluate the plausibility of the volume calculated.

Consequently, we extended the paper dosage calculation task to include extraction of information embedded in guidelines and the use of a labelled container of liquid and measuring equipment. Retrieval of dosage information is included as part of conceptual competences in the competency dosage calculation model used in the Benchmark Assessment of Numeracy for Nursing designed by Coben and colleagues where dosage calculation competence is described as the point of convergence between the overlapping competences of conceptual, calculation and technical measurement competences (Coben, 2010b).

Accordingly our research question was:

Do students calculate and prepare medicine doses better when provided with contextual factors from the workplace in the form of (a) guidelines and (b) relevant equipment.

Method

Ethics and consent

We obtained ethical approval from the University's Biomedical Research Ethics Committee (BE185/09). After we provided written information, and repeated this verbally, each participant gave written informed consent to the publication, in a research journal, of the overall findings from their data.

Setting

The study took place among first year students studying medicine at the Nelson R Mandela School of Medicine, University of KwaZulu-Natal, Durban, South Africa. Students come from a variety of socioeconomic backgrounds and attend a related range of high schools, some fee-paying and some government funded. At admission, quotas are in operation such that preference is given to those from non-fee-paying schools. (University of KwaZulu-Natal (UKZN) Applications and Information Office, 2019).

Within quotas, students are selected according to academic success in the school leaving examination, from which an Academic Performance Score (APS) is calculated by adding the performance levels (1-8) of their top six subjects. A maximum of 48 points is achievable. Students scoring the same number of points within a quota are ranked according to the average percentage achieved. Minimum requirements include a performance level of 5 for Mathematics, Physical Science, Life Sciences and English. Students must have studied English, the language of instruction, at school and it must be either a home or first additional language. Many students do not have English as a home language, and some would not have had English as their language of instruction at high school. These speak one of the other 10 official South African languages.

The 6-year MBChB programme involves a mix of problem-based learning, didactic lectures, clinical bedside teaching, rural attachments and research electives. Intensive clinical training begins after three preclinical years. Candidates are exposed to clinical situations from the first year onwards, with gradually increasing time spent in wards and clinics with increasing responsibility (UKZN College of Health Sciences, 2019).

Dosage Training

The class comprised 262 students. They received ten hours of training, in approximately one-hour-long large group sessions over 3 months. First, we focused on topics which some previous students had found difficult (Harries & Botha 2013b); examples were unit conversions, conversion between common fractions and decimal fractions, and the concept of concentration as an intensive quantity. Gradually we introduced students to new contextual information, such as certain equipment used to deliver medicines to patients. We showed them how to calculate volumes when the concentration was expressed as a weight per unit volume, as a ratio or a percentage. We guided them through worked examples of typical dosage calculation problems, which involved navigation of treatment guidelines (such as the textually-dense guidelines in the SAMF) to retrieve recommended drug doses. Students learnt how to find the dose and formulation concentration for a solution for injection as well as how to retrieve the information needed to dose a liquid syrup to be given to children by medicine spoon or dropper.

Study Design

Following the ten hours of training, 239 students (those members of the class who happened to attend a routine lecture on that particular day) were randomly allocated to one of four groups.

They all received the same question about a medicine called digoxin. They were asked to calculate the dose, and the volume of liquid syrup containing this dose, for a 5kg child on the first day of treatment. This first dose is referred to as the 'digitalising dose' and they had been made aware of this terminology during their training. Besides showing them how to extract the relevant information from formulary excerpts, and how to work out the

volume required, we had also discussed how the daily dose must be divided further into three doses across the day. Students had, in fact, had a similar case during their training involving the same medicine but for a child of a different weight who required a 'maintenance dose', which is the dose used over long periods.

We asked Groups 1 and 2 to only calculate a dose and volume of liquid, while Groups 3 and 4 had to both calculate and prepare the dose and relevant volume of liquid:

Group 1 received numerical information by means of the following question:

> *A boy of 5 kg is to start drug treatment with digoxin. For the first day of treatment, he is prescribed 0.015 mg/kg/day in 3 divided doses of the liquid dosage form/elixir (concentration 0.05mg/ml). Work out the volume of digoxin he should be given for the first dose.*

Group 2 received a formulary excerpt about digoxin copied onto a single A4 page. They had to navigate ten headings to find, and then extract, the appropriate paediatric dose and correct preparation. They received the following question:

> *A boy of 5kg is to start drug treatment with digoxin with a digitalizing dose (for the first day) of the liquid dosage form/elixir. Use the guideline provided to work out the volume of digoxin he should be given for his first dose.*

Group 3 received a 1ml syringe and bottle of formulation (actually tea) labelled 'Digoxin 0.05mg/ml'. The question did not provide the concentration information, which students were expected to take from the label on the bottle.

> *A boy of 5 kg is to start drug treatment with digoxin. For the first day of treatment, he is prescribed 0.015 mg/kg/day in 3 divided doses of the liquid dosage form/elixir. Work out the volume of digoxin he should be given for the first dose. Use the syringe to draw up the correct volume from the bottle provided and leave the syringe containing the prepared dose on your question paper.*

Group 4 received the same formulary excerpt as Group 2, together with a syringe and formulation of Group 3. Their question was:

> *A boy of 5kg is to start drug treatment with digoxin with a digitalizing dose (for the first day) of the liquid dosage form/elixir. Use the guideline provided to work out the volume of digoxin he should be given for his first dose. Use the syringe to draw up the correct volume from the bottle provided and leave the syringe containing the prepared dose on your question paper.*

Students were considered to have been successful if they wrote down the correct volume and units. If they were also given equipment (Groups 3 and 4) they were also expected to draw up the correct volume into the syringe.

Demographics

Table 1 shows the demographics. Less than a third of the students had English as a home language, with students most commonly speaking isiZulu at home. More than half the participants had attended a non-fee-paying school. Although the numbers of students within each of the Groups 1 to 4 were somewhat different for both English home language and type of school attended, a chi-square test for homogeneity revealed that in both cases there was no significant difference.

Table 1

Demographics

Demographic factor	All participants	Group 1	Group 2	Group 3	Group 4
	$N = 239$	$n = 61$	$n = 60$	$n = 59$	$n = 59$
Gender (% male)	50	51	43	54	53
Average age years	19	19	19	19	19
range	17-29	18-25	17-29	18-28	17-24
Academic Performance	40	40	40	41	41
Score range	25-48	27-48	25-50	34-48	35-48
Home language (%)					
English	26	24	17	37	27
Other	74	75	83	63	73
School funding status (%)					
Non-fee-paying	52	52	62	41	51
Fee-paying schools	48	48	38	59	49

Analysis

We used Epi-Info 7.2.2.6. (Centre for Disease Control, 2011) for the analysis. We compared success between Groups 1, 2, 3 and 4 using a chi-square test. We used regression analysis to assess whether performance was influenced by having English as a home language, by attendance at fee-paying or non-fee-paying schools, by provision of equipment and by the need to use guidelines. We also calculated relative risks and their 95% confidence intervals (95% CIs). We considered a Bonferroni adjusted p-value of less than ~~0~~.01 to be statistically significant.

If more students with a home language other than English also have a lower socioeconomic status, this may confound a difference in success seen between students with different home languages. Accordingly, we performed a chi-square test between schooling and success stratified for English as home language.

Finally, we performed a multiple logistic regression including the three variables which were ultimately shown to be significant.

Qualitative assessment of answers

We analysed students' written calculations to try and understand how they were thinking about the problems.

Retrieval ability

We compared Groups 2 and 4 to see if students found the concentration of the formulation more easily when given the label on the bottle in addition to guidelines.

Incorrect units and other mistakes

We assessed all groups to see which students had the most incorrect units or used no units at all. We considered both of these to be incorrect units. We also tried to understand the meaning of incorrect answers.

Unrealistic answers and difference between what was written down and drawn up

We reviewed answers from all groups to see whether what was written down was actually measurable using the equipment (even if the amount written down was incorrect). Answers which were impossible to measure in a 1ml syringe (the correct answer being 0.5ml) were deemed to be unrealistic. In groups provided with a syringe (Groups 3 and 4) we compared what was written down with what was drawn up.

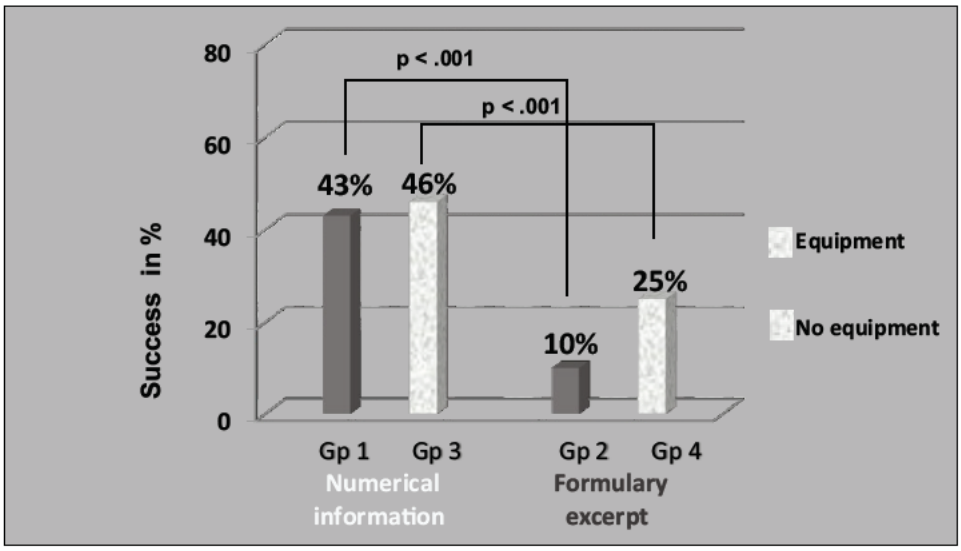
Results

Dosing success

Overall students provided with numerical information (Groups 1 and 3) performed significantly better than those who had to retrieve it from guidelines (Groups 2 and 4), with success rates of 44% ($n = 120$) and 18% ($n = 119$) respectively ($p < .001$). Figure 1 shows the success for individual groups. (Online Resource 1 provides additional data.) Providing equipment, in the form of a syringe and labelled formulation, helped those who were extracting information from guidelines (Group 2 compared to Group 4) but not significantly so ($p = .027$). Overall, there was 26% success ($n = 121$) without equipment and 36% success ($n = 118$) with equipment ($p = .13$).

Figure 1

Percentage of students (N = 239) dosing successfully in each group



Home Language

Students who did not have English as their home language performed significantly worse. Overall they had nearly three times the risk of getting the answer wrong compared to English speakers, relative risk 2.9, 95% CIs [1.97, 4.34], 84% versus 29% incorrect answers respectively ($p < .001$). When provided with numerical information they had a nearly fourfold risk of getting the question wrong, relative risk 3.8, 95% CIs [1.94, 7.54],

72% versus 19% incorrect respectively ($p < .001$). When required to retrieve from guidelines the relative risk was 2.2, 95% CIs [1.41, 3.47], 94% versus 42% incorrect respectively ($p < .001$).

School Attended

Students who had attended a non-fee-paying school were significantly more likely to get the answer wrong with a relative risk of 1.52, 95% CIs [1.27, 1.84] incorrect answers 83% versus 54% ($p < .001$). When given numerical information the relative risk of getting the question wrong compared to those from fee-paying schools was 1.69, 95% CIs [1.22, 2.36], 71% versus 42% incorrect respectively, $p = .001$). When required to retrieve from guidelines the relative risk was 1.34, 95% CIs [1.10, 1.62], 93% versus 69% incorrect respectively ($p < .001$).

Home language and School Attended

When we stratified students according to home language, we found that all those who were English speaking had attended fee-paying schools. For those speaking languages other than English at home, there was no significant difference in success between students attending non-fee-paying schools (83% incorrect answers) and those who had attended fee-paying schools (86% incorrect), relative risk 0.96. 95% CIs [0.84, 1.10], ($p = .59$).

Final Multiple Logistic Regression

When we performed a multiple logistic regression including the three variables which had been shown to be significant, namely English home language, school funding and requirement to extract information from guidelines, English home language, adjusted odds ratio 18.53, 95% CIs [6.62, 51.82], ($p < .001$) and guidelines, adjusted odds ratio 0.23, 95% CIs [0.11, 0.48], ($p < .001$) remained highly significant. School funding lost its statistical significance, adjusted odds ratio 0.70, 95%CIs [0.27, 1.83], ($p = .47$).

Qualitative Assessment of answers

Retrieval ability

Sixty three percent of students (37) in Group 4 were successful in finding the concentration of formulation compared to 38% (23) in Group 2.

Incorrect units and other mistakes

We considered any incorrect unit or no unit at all to be an incorrect unit. In total there were 72 students who had incorrect units, most of them (28) in Group 2. Sixty nine wrong answers were accompanied by incorrect units in contrast to only 3 correct answers. Forty one percent of the students with no access to dosing equipment wrote down the wrong units while only 20% of those given the syringe and 'medicine' bottle, both marked in millilitres, wrote down the wrong units. The most common incorrect unit was mg. Others were mg/ml, mg/kg/day, kg and dm. The most common incorrect quantity was 0.025 and a frequent mistake was having the decimal point in the wrong place.

Unrealistic answers and difference between what was written down and drawn up

Fifty two students gave answers that were too large or too small to have been drawn up in a 1ml syringe. Thirty nine (33%) of these were in Groups 1 and 2 ($n = 120$), three times as many as the 13 (11%) in the Groups 3 and 4 ($n = 118$) which had equipment. Forty three (36%) of the 118 students who were given equipment (Groups 3 and 4) did not draw up the same amount they had written down. Some of

these amounts had the wrong units but nevertheless even the actual numbers did not match up. Twenty five of these students were in Group 3 and 18 were from Group 4.

Discussion

Students who had to calculate the medicine dose using numerical information were successful just under half the time (43%). We were surprised at this low success rate because students had been guided through a very similar calculation, involving the same medicine, during the dosage training that preceded the study. However, perhaps it was those who succeeded who did well as dosage calculations are known to be universally difficult for both medical students and doctors (Wheeler et al., 2010; Simpson et al., 2009).

A possible factor influencing our finding was that this particular dosage calculation did present various difficulties. For example, it required several steps: the daily dose for the child's weight had to be calculated, the volume of liquid formulation containing that dose then had to be worked out and, finally, the daily dose had to be split into three equal doses. In addition, the calculation involved fractions with various different units and, besides that, the actual figures had two and three decimal places.

Another possible reason for the low success rate was that unsuccessful students may not have understood the question properly. Three quarters of our students are not English speaking and indeed our results showed that students who did not have English as a home language had an almost four fold risk of getting the answer wrong. Clearly students' numeracy and literary skills were inadequate, and perhaps their schooling was responsible. Our results confirmed that students from non-fee-paying schools were more likely to get the question wrong compared to those from fee-paying schools (relative risk 1.69).

Students not given numerical information but asked to find it in formulary guidelines had even greater difficulty and their success (10%) was significantly worse ($p < .001$). One explanation for this is that there were additional manipulations involved which provided further opportunities for making mistakes. In addition, the information in the formulary, although it is actually what students will have to use in the work situation, is dense and needs to be carefully navigated. We believe that the very poor performance here is a further indication of inadequate literary skills based on lack of understanding of English, which may derive from imperfect schooling. When required to retrieve from guidelines, the relative risk of getting the answer wrong was 2.2 for non-English speakers and 1.34 for those who had attended a non-fee-paying school.

The fact that native English speakers were at a distinct advantage in our study is not surprising as all assessment forms required quantitative literacy and previous studies have found this to be most difficult for non-native English speakers (Reyna and Brainerd, 2007). What we found surprising was that the English speakers struggled so much with extraction of information from guidelines; while 19% calculated non-embedded questions incorrectly, risk of failure more than doubled to 42% for embedded formats. Students' ability to understand and extract information was poor even though the guidelines were in their own language. All the English speaking students had attended fee-paying schools but this had still not equipped them with the required skills.

We believe that the explanation is the way reading is taught in most South African primary schools. Rule and Land (2017) refer to this as 'oratorical reading' where emphasis is on reading aloud with correct pronunciation but with little ability to understand what is being read. Teachers themselves were taught in this way so perpetuating the problem, which has resulted in South Africa being placed last of 50 countries in the Progress in International Reading Literacy Study (PIRLS) 2016 tests. Similarly, mathematics education in South Africa has largely been traditional and formal, with the focus being on procedural knowledge without encouraging students to make sense of, or question, the procedures (Barnes 2005). We believe this helps explain some of our other findings: when we qualitatively assessed student errors we found that the most frequent incorrect quantity written down was 0.025. This would have been the correct answer if we had asked for the dose in mg rather than the volume of preparation containing this amount. Frequently students wrote 0.025ml as though they thought this was the answer by simply switching units without involving a conversion to volume. They also frequently had the decimal point in the wrong place. All this leads us to believe that they did not 'go back to basics' and conceptualise the problem properly. Perhaps they had been taught some formulas in school rather than understanding the process and were now unable to remember them; this idea would certainly be supported by the fact that some used the most outlandish units.

Seventy two students did not use the correct units, most of them (28) were in Group 2. Incorrect units accompanied more wrong answers (69) than correct answers (3). We believe this is because a general ability to understand what is required in the calculation and do it successfully would also involve using the right units. The most common incorrect units were milligrams, which measured the amount of the medicine required rather than the volume. This finding shows that, despite the concept of concentration being carefully explained with analogies and examples during the training, students still had conceptual difficulties with this intensive quantity. Intensive quantities, which are formed from relating variables proportionally (in this case, the amount of drug to the volume of formulation), have received relatively less attention during schooling (Howe, Nunes and Bryant 2010). In a previous qualitative study of our own, the very weak students struggled with the idea that a ratio or percentage can describe the relationship between the amount of drug in a solution and the volume of that solution (Harries & Botha 2013b).

All students, and especially non-English speakers, require support retrieving embedded information. Hansson (2012) found that results were better where teachers provided scaffolding (support that increased the chance of learning opportunities remaining within a student's Zone of Proximal Development) especially for students who were from a lower socioeconomic background and who did not have English as a home language. We were concerned about whether English confounded socioeconomic status and hence student opportunities. The only measure we had of this was schooling. Interestingly, we found that for those speaking languages other than English at home, there was no significant difference in success between students attending non-fee-paying schools and those who had attended fee-paying schools. Also in our final analysis the only significant predictors of poor performance were non-English speaking and guidelines. We believe therefore that, in addition to the 'oratorical reading' taught in our schools, not being English-speaking is the major reason for our findings.

Although students have a range of home languages, isiZulu was the most common (62%). The effect of offering bilingual instruction for dosage calculation training should be explored. Learning sessions could be recorded for

students to follow after the lecture or they could be translated and recorded in isiZulu. In a previous intervention, involving the inclusion of dosage calculations in repeated formal assessment, same home language peer learning and individual teaching, students' competence with typical problems improved from 23% to 66%, and an initial association between English home language and success was lost by the final assessment (Harries & Botha, 2013b). Similar strategies could also improve success with calculations involving embedded information.

We had expected that provision of equipment would assist students so were surprised that success increased by only 3% to 46% when students were given a syringe and the bottle of 'medicine' in addition to the numerical information (Group 3). A possible reason is that the equipment merely made some of them more confused as other authors have cautioned that including contextual factors in the classroom can add complexity thus confusing students who have not yet mastered the calculation process (Stasz, 2001).

In another study, nursing students were found to perform worse in a simulated situation with drugs and equipment where they had to extract information. Those researchers attributed this to greater possibility of mistakes retrieving information from formularies and making measurement errors (Sullivan & Clarkson, 1982). Interestingly, in our study, students in Group 4, who had equipment as well as guidelines, had more than twice the success (25%) of those with guidelines alone (Group 2). The likely reason is that providing the bottle of formulation, labelled with its concentration, was helpful because it saved students the more challenging task of looking for this information in the formulary guidelines. Indeed our detailed analysis of student answers showed that 63% of those in Group 4 were able to find the concentration of the formulation compared to 38% in Group 2.

Dosing equipment helped protect against use of the wrong units. While 41% of students with no equipment (Groups 1 and 2) wrote down the wrong units, only 20% of those given the syringe and 'medicine' bottle (Groups 3 and 4), wrote down the wrong units. We don't know whether these students simply copied the correct units of millilitres from the syringe or 'medicine' bottle or whether the equipment helped them think about and understand the problem better.

In general students using equipment were less likely to give unrealistic responses. Quantities that were actually measurable using the equipment (even if the amount was incorrect) rose from 67% to 89 % when students used equipment. A possible explanation is that students could better visualise the dose with the help of equipment as was found by Weeks (2001) and Wilson (2003).

However, although it helped, equipment did not ensure absolute success in dosing. We had assumed that students would be able to measure quantities using a 1 millilitre syringe. However, unexpectedly, 43 of the 118 asked to both calculate and draw up the dose drew up a dose which was different to the one they calculated. Six of these calculated the dose correctly but drew up the wrong dose. A typical paper assessment would have rewarded these six, when in fact they are not competent at dosing. This finding supports the case for inclusion of equipment, in assessment not just as a reference, but requiring students both to calculate and draw up doses.

It could be argued that measuring the dose in our simulation may have been unnecessarily difficult compared with that in the workplace because digoxin syrup is usually supplied with a graduated one millilitre pipette (dropper). Although the capacities of the measuring equipment are the same, the gradations on the dropper are simpler, offering less measurement options. However, the use of the syringe can be justified because it is often used in the clinical situation to measure injectable doses and small oral paediatric doses. Students must know how to draw up with both. The ability to measure doses in a syringe should not be assumed.

Consequently, artefacts should be included in learning. We now include visual representations of syringes of different capacities, explanations of how they are graded and a guided tutorial, where students mark off the volume of different doses required and give the volume of quantities indicated on diagrams of syringes. In future training, we plan to provide syringes and 'formulations' for students to draw up a simulated oral dose. This would be a low-cost, feasible intervention with reusable equipment that could form part of students' large group sessions. It would provide a practical experience for students to draw on during paper problem assessment.

Our findings might also be cause for advocating for the provision of equipment in dosing assessments involving retrieval of embedded information, otherwise conditions are more difficult than those in the workplace where both guidelines and equipment are available. We also believe that dosage calculations which require extraction of information should be included in formal assessments. Although our results indicate that this might impact on the number of successful candidates, the fact that students are having difficulty with this important workplace task is a strong reason to include it in formal assessment, as, particularly in medical school, assessment has been reported to drive learning (Newble and Entwistle 1986).

Conclusion

The inclusion of two workplace contextual factors, guidelines and equipment, affected the outcome of assessment. When compared with calculating a typical dose students asked to retrieve information embedded in guidelines were less successful, while drawing up the dose using a syringe made the task of retrieving embedded numerical information and calculating the dose easier. Such contextual factors should be included in teaching and assessment to prepare students for the work they will encounter in the clinical situation. Students who are learning, reading guidelines and being assessed in a language of instruction that differs from their home language are at a further disadvantage and need additional support.

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CHAPTER 6 EXTENDING TUITION FOR PRACTICES DEMANDING MORE COMPLEX PROPORTIONAL REASONING

Research question 4

What proportional reasoning skills do students demonstrate during drug dosage practices of increasing difficulty?

In presenting the findings of the study that answer the fourth research question, this chapter describes the proportional reasoning routines underlying the different student assessments in Cycle III, comparing them to previous cycles. It also presents the findings of the student assessments conducted in Cycle III. At the end of the chapter, three tables (Tables 6.4 - 6.6) provide summaries of the research. Paper 4 follows, in which some of the quantitative findings have been written up.

6.1 Basic proportional reasoning assessment

Of a class of 256 first-year students, 247 (96%) answered the 'basic proportional reasoning' assessment, which comprised six questions involving lower level reasoning and procedural number skills. While the first three questions tested reasoning of the 'missing values' type, and involved contextual information relevant to clinicians, the final three questions were decontextualized and tested fraction conversions and calculating the value of a percentage. In the first, the rate of a birth defect per live births (a_1/b_1) in a population was given and students had to work out the number of babies with this birth defect (c_1) that could be expected when a certain number (d_1) were born at a particular hospital. In the second question, students had to calculate the amount of medicine required (c_2) when given a milligram per kilogram dose (a_2/b_2) and the mass of a patient (d_2). The third question involved working out the number of drops (c_3) into which an administration set with a particular drop factor (a_3/b_3) would convert a volume (d_3) of an infusion. This was the same calculation type as was required in the first part of the infusion rate calculation for one of the questions used in the assessment of typical dosage calculations, discussed in Chapters 3 and 4. While 44% got all six questions correct, 55% correctly calculated the first three questions, which required proportional reasoning. For the procedural numeracy questions 82% answered all three questions correctly. These students then received dosage calculation training and were assessed. Table 6.1 shows each question and the percentage achieved.

Table 6.1 Student success at basic numeracy and proportional reasoning assessment

Question	Percentage success
1. If the ratio of children born with a cleft lip and/or palate is 1:700 and 2100 babies have been born at Hospital X, how many babies would you expect to be born there who have a cleft? (Answer: 3)	82
2. You prescribe a dose of medicine for a 10 kg p atient. If the dose is 2 mg/kg, how much of the medicine must the patient get? (Answer:20 mg)	72
3. If you have an administration set that gives 15 drops/mL and a 50 mL drip, how many drops do you have? (Answer: 750 drops or 750)	70
4. Convert to a decimal fraction: 2/100 (0.02)	92
5. Convert to a common fraction: 0.75 (¾ or 75/100 accepted)	93
6. What is 2% of 500? (10)	91

6.2 Proportional reasoning routines underlying dosage calculations

For the assessments of typical dosage calculation administered to the original cohort of 364 students in Cycle I and to the final class of 256 students in Cycle III, one of the problems involved calculating an infusion drip rate, so that the volume of solution in which the relevant amount of medicine was dissolved would be administered in the appropriate time. This involved using the drop factor of the administration set delivering the infusion to the patient. This value indicates the number of drops produced by 1 millilitre (mL) of infusion solution **(a_4/b_4).** This is usually 15 drops/mL for the adult administration set and 60 drops/mL (producing drops that are four times smaller) for the paediatric set. The volume of the infusion formulation is usually a 50 mL 'minibag' of normal saline so the number of drops in the infusion solution could be calculated by equating the number of drops divided by the volume of the infusion to the drop factor.

The other three questions involved finding what volume of a formulation of a drug in solution was required, or what amount of drug was contained in a formulation. The concentration of the formulation **(a_5/b_5)**, was either expressed as 1) a mass divided by a volume 2) a percentage solution or 3) a ratio. If a volume was required, for 1), a student would be given the amount of medicine ***(c_5)*** needed, and then the volume ***(d_5)*** could be determined. Adding to the proportional reasoning needed, the amount of medicine required was usually provided as a per kilogram dose (***a_6/b_6***), as occurs commonly, especially in children. The mass of the patient (***d_6***) was given and the student would calculate the amount of medicine required (***c_6***). For 2) and 3), the student would need to know that an x% solution implies x grams in 100 millilitres, and that these units are also implied for ratio concentrations. Then the formats could be converted to the mass/volume forms and the student would proceed as in 1). Where the amount of drug in a formulation was required, the student would know ***a_7/b_7***, the formulation concentration, and ***d_7***, the volume of the formulation, so the amount ***c_7*** would be sought.

For the assessment in the second cycle (testing the class of 239 students) where the task of dosage calculation was broadened so that some were also asked to find dosage information and to draw up the required dose in a syringe, students were all given the same scenario. They were asked to determine the required volume of a formulation of a drug in solution for a particular patient. The relationship between the amount of medicine and the volume of the formulation was given as a concentration **(a_8/b_8)** expressed as a mass divided by a volume (0.05 mg/mL). This information was either provided in the paper problem or on the label of a bottle of the 'formulation' or it had to be retrieved from an excerpt of a formulary.

Students would either be given dosage information about the medicine or would have to find this information in the formulary. Then they would need to use this to work out the amount ***(c_8)*** required for the particular patient and from this the required volume ***(d_8)*** could be determined. The quantitative

reasoning required was similar to some of the typical dosage calculations carried out by the first group of 364 students. Because the fictitious patient in the case was a child, the dosage information was given as an amount in milligrams per kilogram per day. This quantity is a rate of a rate, the first rate being (mg/kg) and the second, the quantity calculated per day and so students were expected to require good proportional reasoning skills, or to be able to accurately access and use procedural skills they may have acquired while practicing a very similar example during their training. First, the amount of medicine per kilogram is a rational number 0.015mg/kg (a_9/b_9). Given the patient's weight, 5kg (d_9), the daily amount 0.075mg, c_9 could be calculated. Now considering this amount was an amount per day or per 24 hours (0.075mg/24 hours a_{10}/b_{10}), the dosage frequency d_{10} if given in three divided doses would be 8 hourly, and the amount per dose 0.025mg (c_{10} the same as c_8 above) could be found. The students who had been given a labelled bottle of formulation (0.05 mg/mL – as above) and a syringe would then draw up the dose d_8 of 0.5mL. Along similar lines, students in the third cycle of the curriculum were also formally assessed for the ability to retrieve dosage information and calculate the volume of medicine required.

6.3 Informal (formative) assessment: Making a rational treatment decision

(or avoiding an irrational decision i.e. choosing to take or not to take a treatment consistently irrespective of the way the efficacy information is formatted)

To compare statements involving the risk statistics - absolute risk reduction, relative risk reduction and the Number Needed to Treat rationally, students would have to manipulate the statistics from one form to another. They would need to reason along the following lines: Using the nomenclature of Frith and Lloyd (2016), the absolute risk reduction (which is the difference between two rates, the placebo event rate r_1 and the treatment event rate r_2,) can be written as r_1-r_2. An event is the negative health outcome of interest within a population (a heart attack in this exercise). The event rate is the number of these events as a proportion of a population, the population being the number of people in the placebo and treatment group for placebo and treatment event rates, respectively.

To reformat the absolute risk information provided as a relative risk reduction (which compares risk as a percentage change), the absolute change in risk as a result of the treatment, r_1-r_2, would be considered as a proportion of the original risk. The absolute change in risk would be divided by the placebo event rate r_1 and multiplied by 100 to express the relative risk reduction as a percent: r_1-r_2 /r_1 x 100. The absolute risk statement, now reformatted in terms of relative risk, could then be compared with the statement involving relative risk and found to be the same.

The third statement involved treatment risk formatted using the NNT statistic. Reasoning of the 'missing value' type could be used to format this as an absolute risk reduction: To prevent one event

(a_{II}), 71 people needed to be treated ***(b_{II})***, so when 100 ***(d_{II})*** people were treated, the value c_{II} could be determined. This was the number of people spared a negative health event out of a population of 100 treated people, i.e. the absolute risk reduction expressed as a percent. This would be found to be the same as the absolute risk reduction in the statement describing risk in absolute terms. Consequently, if students manipulated the three statements providing efficacy of the treatments they were to consider in this way, they would have found that all the statements could be shown to be describing the same risk in different ways.

Of the 256 students in Cycle III, a convenience sample of 157 students, who were present at a lecture session when the formative assessment was administered, participated in this first informal assessment. Of the 157, only 20% made the same treatment decision for all three risk statements. This intervention was designed to surprise students to get their attention and to alert them to how easy it is to be fooled by different risk formats, as quantities are often taken at face value. This was done in the hope of motivating students to think critically about what the numbers mean and why they might be formatted in a particular way. After the second formative assessment, students were given feedback. They were shown how some of the treatment risk statistics could be reformatted as different risk statistics, and how the information could be presented graphically. The table of results from the original study was also provided, and students were shown how to work out the risk statistics from these original figures.

6.4 Informal (formative) assessment: qualitative interpretation of graphical information

The proportional reasoning underlying the graph comparison require quantifying the relationship between two rates qualitatively. This fits Frith and Lloyd's (2016, p. 5) description of the reasoning underlying some of the types of questions they asked their students. They state:

> "Given two rates (fractions) of the form $r_1=n_1/d_1$ with the two values for r (or n or d) not specified, deduce the relative sizes of these unspecified values. The reasoning involves comparing the relative sizes of the given quantities (n_1 *vs.* n_2 and d_1 *vs.* d_2 say) in order to describe the relationship between the other quantities (r_1 and r_2, say). In some cases, the comparison involves only saying which is bigger, but in other cases the question is of the form "How many times bigger or smaller…". Thus these questions do not only require determining the order relationship, but also quantifying the relationship (by estimation)."

This question was answered by 175 students. While nearly all recognised that the treatment group had a lower risk of having a heart attack than the placebo group, their detailed written comparison of the two rates was quite varied. The maps in the two tables that follow, created according to threshold concept theory (Meyer & Land, 2003), positions them in relation to crossing the threshold into competent proportional reasoning from what their responses revealed about their reasoning. The results are presented in Table 6.2: *Students' comparison of two event rates represented graphically: preliminal spaces* and Table 6.3: *Students' comparison of two event rates represented graphically: liminal and threshold spaces*.

Table 6.2 Students' comparison of event rates graph: Preliminal spaces

Adapted from the framework for analysing proportional reasoning questions (Frith & Lloyd, 2016)

Question structure: Given two ratios (fractions) of the form $r_1=n_1/d_1$ and $r_2=n_2/d_2$ (the two values of r specified), describe how the second (smaller) rate relates to the larger rate (n = 175)

CODE	Description	Notes	Example/s of student response from questio	Position relative to liminal scale	Percentage (%)	
Pre- A	Misunderstood quantity (rate) represented by histograms	For example, understood histograms to represent two different concentrations of formulations or the number of doctors within each group	1.'A difference in the concentration levels and its effectiveness. Percentage difference of 0.5' 2.'The physicians taking the drugs tended to be 3/4 of the physicians taking placebo, which makes the drug taking physicians fewer' 3.'More placebo taken by physicians than drug. Drug used is 75% of placebo'	Preliminal because the rates represented by the histogram are incorrectly understood (see example 1) or not understood as rates but as absolute differences between the study and placebo group in the number of physicians (see example 2) or in the number (or %)of people taking placebo compared with drug	5	**23**
Pre-A	Misinterpreted rates	For example, interpreting treatment outcomes as indicating better outcome with placebo	'Placebo increases the chances of physicians not suffering that much as compared to the ones taking drug"	Preliminal because reasoning involving numbers is absent and misunderstood treatment outcomes	1	
Pre-A	No numeric comparison		'I would describe this difference as that it is caused by the effect of the drug'	Preliminal, because reasoning involving numbers, is absent	17	
Aabsolute insufficient numerical		Missing numerical information/numerical errors	'I would describe it as 0.5 less than placebo'	Preliminal, because reasoning involving fractions is absent	3	**44**
Aabsolute insufficient language		Steps in argument are missing, or in simpler questions, linking language is absent	'An appropriate difference of 0.5% which is positive'	Preliminal, because reasoning involving fractions is absent/language insufficiently articulate	6	
Aabsolute ambiguous	Ambiguous Comparison of the rates in absolute terms	For example, absolute reasoning but written so that it would be a relative comparison	'The drug reduces the rate of MI compared to the placebo by 0.5%'	Preliminal, because reasoning involving fractions is absent	24	
Aabsolute	Compare the sizes of the ratios in absolute terms		'2-1.5 = 0.5% less'	Preliminal, because reasoning involving fractions is absent	11	

Table 6.3 Students' comparison of event rates graph: Liminal & threshold spaces

Adapted from the framework for analysing proportional reasoning questions (Frith & Lloyd, 2016)
Question structure: given two ratios (fractions) of the form $r_1=n_1/d_1$ and $r_2=n_2/d_2$ (the two values of r specified), describe how the second (smaller) rate relates to the larger rate (n = 175)

CODE	Description	Notes	Example/s of student response from question	Position relative to liminal scale	Percentage (%)	
$E_{ambiguous}$	Ambiguous comparison of the rates in relative terms	For example, relative reasoning but written so that it would be understood as an absolute comparison	'the rate of MI in drug physicians is 3/4 while that of placebo is 4/4' '75% with drug but if placebo 100% so it less by 25%'	In the liminal space	1	
$E_{incorrect}$	Comparing the ratios and quantifying, but incorrectly		'Fewer by 20%'or 'MI occurs 3/4 (75%) less in patients taking the drug'	In the liminal space	5	
F	False reasoning	For example, not recognising that though drug group 25% less than placebo group, placebo group not 25% more than drug group (i.e. 1-3/4≠4/3-1)	'The rate of myocardial infarction in physicians taking placebo is 25% more than that of physicians taking the drug'	In the liminal space	5	**23**
D	Relative reasoning but imprecisely articulated		'Drug is 25% less than placebo'	In the liminal space	12	
G	Correct conclusion, well articulated		'Physicians taking the drug for 5 years have 25% fewer MI than physicians taking placebo'	At (or over) the threshold		**10**
	Blank (n = 18) and incomprehensible responses (n = 4) were excluded from this analysis and are not included in the 175					

Students were grouped and labelled (between A and G) according to which of the groups in Frith and Lloyd's (2016) proportional reasoning framework they most resembled, with some additional subgroups (added as subscripts) relevant to our case. Those considered to be demonstrating an earlier level of reasoning than the students grouped in Group A were assigned to a Pre -A group.

Only 10% of students compared the graphs correctly and articulately in relative terms, demonstrating that they had crossed the threshold to dosage competence, while an additional 23% showed evidence of reasoning along relative lines and could be said to be within the liminal space toward crossing the threshold. Most students (44%) compared the graphs in absolute terms, with 11% comparing the rates articulately and correctly. Twenty four percent described the risk so that the absolute risk difference would be misinterpreted as a relative risk difference. The event rates were not described in numerical terms at all by 17%, and 5% misunderstood the quantity represented by the histogram to be the number of doctors in each group, the amount of drug versus placebo or the differences in the concentration of treatment provided between the two groups.

6.5 Formal assessments: dosage calculation assessments

Of 127 students who wrote the final examination (these were the students who did not achieve an exemption in the end of theme test), 66% achieved dosage competence for the typical questions. If each question presented to each student were considered to be a potential patient, and this number were compared to the number of opportunities the students had to dose patients, then the percentage of 'patients' successfully treated was 68%. For the embedded questions, 10% got all eight questions correct, while 50% scored at least four questions correct, achieving competence at the 50% level. As there were two paper cases, each involving one patient and with four questions, the 127 students could each be considered to have treated two potential 'patients', 254 patients in all. Altogether 76% of these 'patients' received the incorrect dose at least once, and consequently 24% received the correct dose every time.

6.6 Formal assessments: assessment of ability to work with treatment risk statistics

6.6.1. Proportional reasoning routines underlying treatment risk statistics assessments

In order to make sense of the two event rate chart questions, students were first required to use the event rates to determine the relative risk and relative risk reduction in order to select the correct statistic from the options provided. As for the informal rational treatment selection assessment, students needed to understand that the relative risk described the treatment event rate divided by the placebo event rate and that relative risk reduction involved the difference between the treatment event rate and the placebo event rate as a fraction of the placebo event rate. The relative risk would be r_2/r_1, where r_1 was the placebo event rate and r_2 was the treatment event rate. The relative risk would be represented as the absolute change in risk as a result of the treatment, r_1-r_2 as a proportion of the original risk: r_1-r_2/r_1

The values calculated (a_5/b_5) would then need to be compared with the options provided (c_5/d_5) to determine if they were the same or not. For the second question students needed to determine the absolute risk reduction and the number of patients that would need to be treated to prevent one event (the number needed to treat or NNT). This would requir e the situational knowledge that the absolute risk reduction is the difference between the placebo event rate r_1 and the treatment event rate r_2, i.e. r_1-r_2 and then comparison of the value calculated (a_6/b_6) with the options provided (c_6/d_6) to determine that they were not the same $(a_6/b_6 \neq c_6/d_6)$. In order to determine the NNT, the absolute risk reduction r_1-r_2 would be calculated as above. However, students would now also need to understand that this absolute risk reduction referred to a rate (a_7/b_7): the number of people (c_7) that were saved from having a heart attack out of the population treated (d_7). This rate (0.02) could also be thought of as a common fraction, as two people saved (a_8) out of every 100 treated (b_8). In order to prevent one event (c_8), the number of people that would need to be treated (d_8) could then be calculated. This number could then be compared with the options available and a selection made.

For the formal rational treatment selection question, the efficacy of the first drug w as described in absolute risk terms, describing the placebo event rate r_1 and treatment event rate r_2 and the absolute risk reduction r_1-r_2. That of the second drug was described as a relative risk reduction r_1-r_2/ r_2. The format of the statistic used to describe the first drug could be changed to a relative risk reduction by dividing the risk reduction by the placebo event rate and multiplying by 100 to express the relative risk reduction as a percentage. Thus, the efficacies of the two drugs could be comp ared. The two relative risk reductions could be thought of as a 'Comparative type' proportional reasoning problem, with a_9/b_9 being the relative risk of the first drug and c_9/d_9 being the relative risk of the second. Students needed to determine that $a_9/b_9 > c_9/d_9$, and that the second drug would not be a rational choice. The efficacy of the third drug was given in the NNT format. Reasoning of the 'Missing Value' type could be used to format this as an absolute risk reduction: to prevent one event (a_{10}), 250 people needed to be treated (b_{10}), so when 100 (d_{10}) people were treated the quantity c_{10} could be determined. This was the percentage of people spared a negative health event, in other words the absolute risk reduction expressed as a percent. This rational number (a_{11}/b_{11}) could be compared with the absolute risk reduction for the first treatment (c_{11}/d_{11}) and in this case as $a_{11}/b_{11} < c_{11}/d_{11}$, the first drug was found to be the most effective.

6.6.2 Student success

There were 231 participants. For the treatment chart interpretation, the relative risk/relative risk reduction question was answered correctly by 26% (which was 42% of the 139 students who attempted the questions i.e. did not leave the response option blan k), while 6% (13% of 97 students trying the absolute risk/ NNT) were successful. Sixty students (26%) made a rational treatment choice. As a result 74% of potential patients would have been prescribed a suboptimal drug and potentially harmed. Only

four students were able to answer the two treatment chart questions and the rational treatment choice questions correctly.

6.6.3 Associations for rational treatment selection

Not being an English mother tongue speaker was associated with an inability to use statements involving different treatment risk statistics to select the most effective treatment choice (relative risk 1.4;95% confidence interval 1.1-1.7; 79.6% *vs.* 58.2%; $n = 231$; $\chi^2 = 10.06$; $p = 0.001518$). When only the students who tried the question are included, the association remains (relative risk 1.6; 95% confidence interval 1.1-2.3; 70% *vs.* 44%; $n = 161$).

Answering either of the treatment chart questions correctly predicted success with the rational treatment choice. For both the relative risk and the absolute risk questions, students answering correctly were twice as likely to make a rational treatment choice (relative risk 2.2; 95% CI 1.5-3.4; 44% *vs.* 19%; $n = 231$ for the relative risk question, and relative risk 1.9; 95% CI 1.2-2.7; 56% *vs.* 30%; $n = 231$ for the absolute risk question). When only students who answered the questions were included the association remained for relative risk (relative risk 1.8; 95% CI 1.2-2.8; 60% *vs.* 33%; $n = 109$) but not for absolute risk (relative risk 1.1; 95% CI 0.6-2.1; 50% *vs.* 46%; $n = 78$).

Rational treatment selection was unrelated to basic proportional reasoning test success, dosage calculation competence, mean embedded calculation scores, attendance at the informal treatment selection assessment, having a Pre A rating according to threshold concepts, crossing the threshold, or answering correctly and articulately (either in absolute or relative terms).

Only two students who showed dosage competence in the Cycle III assessment of the typical dosage calculations were also able to make a rational treatment choice. No one who reached dosage competence also answered the two results chart and the treatment choice questions correctly.

6.6.4. Shortcomings

6.6.4.1 Sampling

Sample sizes differed and for the formative assessments were as low as 60% of the class size. As they were a convenience sample of the students who attended a particular lecture they were not representative of the population, Cohort III.

6.6.4.2 Basic proportional reasoning questions

These questions did not form part of a tested instrument. It would have been useful to include the general numeracy assessment tool of Lipkus and colleagues (2001), as this has been used in many studies and

so would have enabled us to compare our students' skills with the participants of those studies. Likewise, it would have been interesting to include Frith and Lloyd's (2016) questions that were included in the South African National Benchmark test to measure qualitative proportional reasoning.

6.6.4.3 Formative assessment: avoiding a rational treatment decision

While choosing differently for the different risk statements would indicate the student had been misled by the figures in the treatment risk statistics and had prescribed rationally, it was not possible to say whether the student had prescribed rationally as their choice might have been motivated by , for example, being extremely open to, or averse to, taking medicine. Besides sampling differences, this prevented quantitative comparisons between this assessment and the formal rational treatment decisions from being made.

6.6.4.4 Formative assessment: graphical comparison

Students might have been misled by the language in the assessment question 'I would explain this difference in detail', taking it to mean absolute risk reduction was required when in fact a relative relationship was sought. Consequently, some students who would have been able to describe the relationship in relative terms might have instead described the absolute risk and so not demonstrated their proportional reasoning.

6.6.4.5 Formal assessment: results chart

The question was designed as a multiple-choice question of the 'Choose the Correct Option' format. This question would have worked better in the 'Fill in the Bank' format. The second question assessing knowledge of the absolute risk reduction statistic also offered options about the Number Needed to Treat and it became impossible to separate knowledge of one from the other. This may have contributed to the difficulty of the question.

6.6.5 Conclusions

Most students have not yet crossed the threshold to reasoning proportionately. They also struggled with the tasks of interpreting the treatment comparison table to evaluate treatment risk statistics and with rational treatment selection, with less than 50% of students succeeding in each of these tasks. In comparison, students did better with the typical dosage calculation questions which involved less complex underlying proportional reasoning skills, with 66% of students being able to show competence with typical dosage calculations. When required to retrieve information from guidelines, however, success fell dramatically, perhaps as a consequence of the comparatively greater literary skills required. A discussion of the results as they relate to language ability forms the content of the next chapter.

Table 6.4 Research summary quantitative part 1

Research question: What **proportional reasoning** skills do students demonstrate during drug dosage practices of increasing difficulty?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Quantitative Cross-sectional study	Students answered 3 **basic proportional reasoning** questions	*n* = 247 1st year students (Cycle III)	55% got all 3 correct**** **Provided information about the proportional reasoning skills students bring to medical school**
Quantitative Cross-sectional study	Students were asked to imagine they were at risk for heart attack. They **decided if they would take each of 3 treatments,** the efficacy of each described by a different treatment risk statistic. The statistics were later revealed to describe the same risk	*n* = 157 1st year students (Cycle III) This was a convenience sample of the class of 256 (those present during teaching session)	20% made the same decision for all three risk statements, so at least 80% could not interpret the statistics to make rational treatment decisions**** **Gauged students' initial level of understanding of skill requiring proportional reasoning while driving home the need to scrutinise numbers not blindly accepting figures at face value**
Quantitative Cross-sectional study	Students worked out 12 **typical** dosage calculations (at least 2 of each type) in a formal assessment. Students getting one of each question type right were deemed competent	*n* = 127 1st year students (Cycle III) a convenience sample (of the class of 256) who wrote the end of year examination (those that were not exempt or sick)	66% were deemed competent 68% of 'patients' received correct treatment /32% were potentially harmed **Students' success could be compared with their success at the drug dose practices (interpreting treatment risk, rational treatment selection) requiring more difficult proportional reasoning**
Quantitative Cross-sectional study	Students answered four dosage calculation questions for each of two hypothetical cases, each requiring **retrieval** of numerical information from guidelines		10% answered all questions for both cases correctly 50% answered all questions for one of the cases correctly 24% of 'patients' got right dose/76% potentially harmed **Students' success can be compared with their success at the drug dose practices (interpreting treatment risk, rational treatment selection) requiring more difficult proportional reasoning but less linguistic ability**

**** Included in Paper 4

Table 6.5 Research summary quantitative part 2

Research question: What **proportional reasoning** skills do students demonstrate during drug dosage practices of increasing difficulty?

Research type	Task undertaken by the students or researchers	Sample academic level (n)	Contribution to the understanding/resolution of the problem
Quantitative Cross-sectional study	Students were asked to interpret part of an event rate chart to determine different treatment risk statistics. First, they needed to use the event rates to calculate the relative risk and relative risk reduction in order to select the correct answer. Next, they had to work out the absolute risk reduction and the NNT in order to choose the right answer	*n* = 231 2nd year students (Cycle III) This was a convenience sample of the class of 256 First Year students (those that had passed to the Second Year and who participated in the end of theme formal assessment)	Relative risk/relative risk reduction question: 26% success*** Absolute risk/ NNT question 6% success**** **Findings gauged students' ability, after tuition, to use proportional reasoning to make sense of a results chart and helped the teacher assess how the curriculum should be adapted to prepare students to leave the preclinical years able to interpret treatment charts**
Quantitative Cross-sectional study	Students had to make a rational treatment selection when given three statements describing the efficacy for each of three different treatment options, each using a different risk format. One treatment option was more effective and therefore was the only rational choice.		26% success**** 74% potential patients harmed **Findings provided evidence of students' ability after tuition in an essential skill requiring proportional reasoning and helped the teacher gauge how aligned the curriculum is to equip students with the necessary workplace competences**

74 **** Included in Paper 4

Table 6.6 Research summary qualitative

Research question: What **proportional reasoning** skills do students demonstrate during drug dosage practices of increasing difficulty?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Qualitative **Thematic analysis** of responses according to predesigned conceptual framework (threshold concepts theory, phenomeno-graphic technique)	Students had to **interpret a graph of two event rates** of a treatment and a control group, to **compare and describe them qualitatively.** The researcher determined what their responses revealed about where their **reasoning was positioned** in relation to **crossing the threshold into competent proportional reasoning.** This was used to **create a map** based on Frith and Lloyd's proportional reasoning framework (2016)	*n* = 175 1st year students (Cycle III) This was a convenience sample of the class of 256 (those present at the teaching session)	10% of students compared the graphs correctly and articulately in relative terms ie they crossed the threshold to competence 11% compared the rates articulately and correctly in absolute terms ie they may have threshold competence but did not demonstrate it in their response 23% showed evidence of reasoning along relative lines and were ranked within the liminal space toward crossing the threshold. Most (44%) compared the graphs in absolute terms **Reveals students' ability to reason proportionately qualitatively without being able to fall back on an algorithm to calculate quantitatively. This allows reasoning ability to be measured rather than procedural skills**
Qualitative document analysis of assessment questions	Researchers assessed the difficulty of the proportional reasoning of the drug dosage tasks assessed by breaking down the proportional reasoning routines to compare the number of 'missing value problem' and 'comparison problem' routines they comprised	Drug dosing tasks in assessments for Cycle I 3rd→4th year students (*n* = 364) Cycle II 1st year students (*n* = 239) Cycle III 1st→2nd year students (*n* = 256)	Proportional reasoning routine descriptions underlying each dosing skill assessment question **allows the complexity to be seen and compared** to other questions. It also **communicates to a reader who is not familiar with health risk statistics** how the numbers must be manipulated to reason proportionately in order to interpret these statistics and use them to make a treatment decision The basic proportional reasoning questions were less complex than the dosage calculations, which were less complex than the risk interpretation and treatment choice questions.

Paper 4: Can medical students make sense of treatment risk statistics?

CAN MEDICAL STUDENTS MAKE SENSE OF TREATMENT RISK STATISTICS?

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ABSTRACT (238 words)

Background Risk statistics are difficult to understand and to explain. We aimed to assess the ability of multilingual medical students to interpret treatment risk statistics and use them to make rational treatment decisions.

Design Preclinical South African medical students were asked whether they would take a medicine based on data presented in three different risk formats. After training, they were reassessed. They had to interpret information regarding risk in relative terms, as an absolute value or in terms of the Number Needed to Treat. Their ability to make a rational medicine choice was also tested.

Results Initially less than 20% of a convenience sample of 157 made the correct treatment decision. For the reassessment, 42% of the 231 students could deal with relative risk, but only 13% could understand absolute risk and number needed to treat. Sixty students made a rational drug choice and English, as a home language, was a predictor of this success.

Limitations In the reassessment, it was not possible to distinguish between ability to understand absolute risk and numbers needed to treat. The readability of one of the risk statements could have been improved. As these were students no real decisions had to be made.

Conclusions

Despite training, students still struggled with different risk formats. English as a home language was a predictor of making a rational choice and it appears that understanding information in a non-mother tongue may be the main problem.

INTRODUCTION

Patient-centered care involves patients in shared health decision making. A key component of this is providing patients with unbiased treatment risk statistics in a format that is easily understood.[1] This skill is critical for patient satisfaction and a healthy doctor-patient relationship.[2]

In order to communicate evidence-based risk information effectively, doctors must first choose treatment options that are optimum for the patient. This is not easy. Judgments must be made under uncertainty, often with high stakes involved, such as whether or not a potentially dangerous intervention would be in the patient's best interests.[3] Once the doctors have decided, they must then communicate the quantitative probabilistic information, which often involves small numbers, in a way that best assists patients in making an informed medical decision at a stressful time. This has been described as an 'extremely challenging task'.[3]

Risk probabilities are expressed in different numerical formats in the literature and in advertisements. They must sometimes be converted from one to another, for example, to compare efficacy data for two treatment options. Treatment efficacy may be presented in absolute terms: for example "the treatment reduces 41 cases of heart attack to 27 if 1000 people are treated for 5 years". The *absolute risk reduction* (ARR) is the difference in the event rate between the control group and treatment group, in this case 14 cases of heart attack would be prevented if you treat 1000 people for 5 years (expressed as a frequency),

so the ARR is 14/1000 (expressed as a rate) or 1.4% (expressed as a percentage). The inverse of the ARR is the *number needed to treat* (NNT), an estimate of the number of patients who must be treated in order that one will benefit. So 1000/14 =71.4, therefore 71 patients. The *relative risk* is the numerical relationship between the events in each group, so 27/41 is roughly 2/3. The treatment group experienced two thirds the heart attacks that the control group did, so the *relative risk reduction* (RRR), the difference between these risks as a proportion of the risk in the control group is 41-27/41 or 14/41, often expressed as a percentage (34% in this example).

Patients[1,2,4-9,14,15] and doctors[2,4,10-15] have trouble with these risk formats. Their understanding[1,6,15] and their motivation to use a medicine[2,4-12,14,15] based upon different formats varies depending on which they are presented with, and whether a baseline level of risk is included.[6] One study that included student interns also found that perceptions of therapeutic effectiveness differed, depending on the format in which the trial results were presented. [16]

Among preclinical medical students, Chao *et al.* found that the method used to present information influenced treatment decisions. [17] Sheridan *et al.* investigated a group of 61 first year medical students. As part of a pilot study focused on the numeracy of medical students, they were asked to compare and calculate treatment risk when given different risk formats. [18] Apart from these studies, there is no information about whether medical students can interpret risk statistics to make a rational treatment choice. There is also a paucity of studies among non English speakers and students of other race groups.[15,17] Consequently our study aimed to assess the ability of multilingual medical students to interpret treatment risk statistics and use these to make rational treatment decisions.

METHODS

The study was conducted among medical students at the Nelson R Mandela School of Medicine, University of KwaZulu-Natal, Durban, South Africa. Students were informed about the study and, before participation, gave written informed consent. The study was approved by the University's Biomedical Research Ethics Committee (reference number BE185/09). The group comprised the first year class of 2013. At the beginning of the year students were assessed for their proportional reasoning skills and their ability to evaluate risk. After training they were reassessed, in their second year, with regard to understanding risk and making a rational treatment decision.

Proportional reasoning assessment

Students were asked to answer the 6 questions shown below.

1. If the ratio of children born with a cleft lip and/or palate is 1:700 and 2100 babies have been born at Hospital X, how many babies would you expect to be born there who have a cleft? (Answer: 3)
2. You prescribe a dose of medicine for a 10 kg patient. If the dose is 2mg/kg, how much of the medicine must the patient get? (Answer:20mg)
3. If you have an administration set that gives 15 drops/mL and a 50 mL drip, how many drops do you have? (Answer: 750drops or 750)

4. Convert to a decimal fraction: 2/100 (0.02)

5. Convert to a common fraction: 0.75 (¾ or 75/100 accepted)

6. What is 2% of 500? (10)

The first three questions were short paper problems, while the remaining three questions tested lower level skills: fraction conversions and calculating the value of a percent. The percentage of students getting each question correct, getting the first and second three questions correct and all 6 questions correct was evaluated.

Initial Risk Assessment

Students were tested using a scenario and questions published by the Therapeutics Initiative.[4] They were asked to imagine they had a risk factor for a disease and that a drug treatment was available with minimal adverse effects. They were given three statements, each involving a different treatment risk statistic, namely RRR, ARR and NNT. For each statement they were asked whether they would be motivated to take the drug based on this information. They were not told that the statements each described the risk from the same study.

Training

During their first and second years, the class received training in interpreting risk statistics. They were given the definitions of RRR, ARR and NNT and shown how these could be calculated using event rates described in tabular and graphical forms. They were also shown how one statistic could be converted into another. The statements in the initial assessment were then shown on a graph to demonstrate to students how they represented results from the same study.

Reassessment

In the final exam in their second year (2014) students were required to answer three questions. Two questions related to the events rate chart below, and students were required to choose the best answer in each case. The first tested ability to interpret RRR correctly and the second ARR and NNT. In the third question, they had to make a rational choice from three statements describing treatment outcomes, each involving a different drug described by a different risk statistic, drug A relating to ARR, B to RRR and C concerning NNT.

Event rate chart and questions 1 and 2

Use the events rate chart below to answer the following **TWO** questions:

Clinical Trial	Placebo group: number of patients			Drug group number of patients		
	Total	Event (heart attack)	Event rate	Total	Event (heart attack)	Event rate
	2000	160	0.08	3000	180	0.06

Choose the best option in each of the two questions:

First Question

A. The relative risk is 0.02.
B. The relative risk reduction is 75%.
C. The relative risk is 0.75.
D. The relative risk reduction is 0.02.

Second Question

A. The absolute risk reduction is 0.25.
B. The absolute risk reduction is 0.06.
C. The number needed to treat is 50.
D. The number needed to treat is 5000.

Rational choice question (question 3)

Your patient is adhering to non-drug treatment to reduce his risk of having a heart attack. He now needs additional drug treatment. You receive information about three treatment options (drug A, B and C). All of the drugs have minimal adverse effects and are equally well tolerated. Which drug would be the rational choice to recommend to your patient if:

A. 1% of patients taking drug A for 5 years had a heart attack compared with 1.5% taking a placebo, a difference of 0.5%.
B. Patients taking drug B have 20% less heart attacks than patients taking placebos.
C. If 250 patients took drug C for 5 years, this drug would prevent 1 patient from having a heart attack. There is no knowing in advance which person this might be.

Choose the MOST CORRECT option:

1. Drug A is the rational choice because it is the most effective
2. Drug B is the rational choice because it is the most effective
3. Drug C is the rational choice because it is the most effective
4. They are all of similar effectiveness, so the cheapest of these would be the rational choice

Data and Statistical Analysis

Initial Risk Assessment

Responses were analysed using Excel® and Epi-Info®, version 3.5.3, a public domain statistical software package for epidemiology (Centre for Disease Control and Prevention, 2011). Students who had responded either always yes or always no, for all three statements, and could be reached were followed up telephonically.

Reassessment

Students who succeeded in the rational choice question were characterised further using Excel and Epi-Info[19] to test for associations. chi-square tests, risk ratio calculations and *Student T-Tests* were performed, with statistical significance set at a level of 5% or less (i.e. $p < 0.05$). The readability of the assessment questions were measured using the Flesch-Kincaid grade level scale available as part of the MS Word 2007® package. A low grading is considered more readable than a higher grade the optimal range being 9 and below. The rational choice question's readability was measured as a whole and then each risk statement was measured individually.

RESULTS

Proportional reasoning assessment

From a class of 256 students, 247 participated. Success ranged between 70% (question 3) and 93% (question 5). Forty four percent of students answered all six questions correctly, 55% answered all three paper problems (questions1-3) correctly and 82% answered the procedural problems (questions 4-6) correctly.

Initial Risk Assessment

From the 256 students, a convenience sample of 157 students was drawn. All of these responded to all the questions. Of these, 79%, 55% and 26% were convinced to take the drug based on the RRR, ARR and NNT information respectively. Only 20% of students responded in the same way to all three options, being either always or never motivated to take the drug. Although this was the correct answer, when 13 were contacted telephonically, none recognised that the three options described the same risk. In other words, although they had given a 'right' answer they hadn't been rationally motivated.

Training

The whole class ($n = 256$) participated in some or all of the training.

Reassessment

Of the original first year class of 256, 231 students (90%) were available to be reassessed at the end of their second year. Their average age was 20 (range 18-31), 58% were female, 24% spoke English as a mother tongue and 42% were required to attend academic literacy classes. These demographic profiles did not differ statistically from those of the 157 students who had participated in the initial assessment.

The 221 students who also attended the proportional reasoning assessment scored an average of 46% for this assessment.

The readability of our events rate chart questions 1 (RRR) and 2 (ARR & NNT) was found to have a Flesch-Kincaid grade level of 9.0. The rational choice question (question 3) performed better overall, with the Flesch-Kincaid grade level calculated to be 6.0. However, when the readability of each individual drug and risk statement A, B and C in question 3 was calculated, A (ARR) performed most poorly (grade level 11.8) compared with B (RRR) and C (NNT) statements (grade levels 7.6 and 5.6 respectively).

The findings are presented in the first column of Table 1.

As many students omitted one or more of the questions, possibly due to time constraints or negative marking, the data was reanalysed using only students who had attempted the questions. See second column of Table 1.

Table 1: Students answering the three reassessment questions correctly

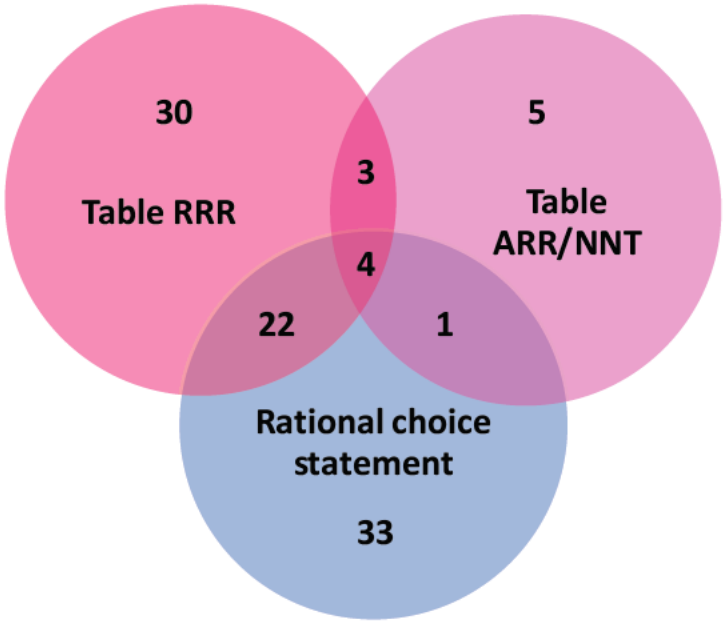
Question	**Number of students answering correctly** (n = 231)	**Students answering correctly out of those who attempted the question**
Q 1 RRR	59/231 (26%)	59/139 (42%) (n = 139)
Q 2 ARR & NNT	13/231 (6%)	13/97 (13%) (n = 97)
Q 3 Rational Choice	60/231 (26%)	60/161 (37%) (n = 161)

The 60 students who answered the rational choice question correctly were compared to the 101 students who made an irrational choice. Not having English as a home language was a predictor for making an irrational drug selection. For the students who did not have English as a mother tongue, those who had attended an Academic Literacy programme performed no differently from those who had not attended these classes. Neither success in any of the proportional reasoning questions nor in all six proportional

reasoning questions predicted rational prescribing success. There was no link between success in the reassessment and attendance at the initial assessment.

The number of students with correct answers to the different questions 1, 2 and 3 are presented in Figure 1.

Figure 1: Number of students with correct answers



For the four students who got all three questions correct, all were aged from 19 to 20 and three were male. Two did not have English as a home language, but both of these had attended academic literacy training. Three of the four had attended the initial assessment where all had made irrational prescribing decisions.

DISCUSSION

Prior to any training it seemed that 20% of students were able to make a rational choice. However, even this was an over estimation of their ability as, when a third of these were questioned closely, none realised that the three statements had represented the same risk.

These results are not unexpected. In a similar assessment, Forrow *et al* [12] asked 235 physicians whether two different formats of the same treatment risk would motivate them to prescribe the treatment. Fifty four percent responded the same way to the two formats suggesting that they were going to make a rational choice. The literature reports consistently that doctors, trainees and patients respond differently to different formats describing the same risk. [1,2,4-12,14,15] Even health authorities have been found to make irrational decisions responding differently when treatment results were formatted in different ways. [20]

In our initial assessment, students were most motivated to take a drug when its effects were presented as a RRR. This finding is consistent with the literature which invariably reports that patients and clinicians are most persuaded to initiate treatment, or rate its efficacy most highly, when the RRR format

is used. [1,2,4-12,14,15] It seems that people generally don't convert risk statistics from one form to another in order to compare them, and are much more likely to take the numbers (generally bigger for RRR) at face value.[21] Risk rates involve a numerator (the number of individuals who could benefit) and a denominator (the total population at potential risk) and differ in their persuasiveness depending on whether the affected individuals or the total population at risk is emphasised. Because the denominator is not included in the RRR, the number of individuals likely to benefit is stressed and the information about the total population is lost and this influences behavior accordingly. [22]

For the events rate chart questions during reassessment, our students performed better when interpreting the RRR than ARR and NNT information. It was impossible to tease out here whether NNT contributed most to the poor success rate, or if both ARR and NNT were equally poorly understood, and this is a study shortcoming. In other studies involving interpretation of NNT, it was also found to be less well understood than RRR (while ARR was understood as well as RRR).[1,13] Gigerenzer *et al.*[23] have questioned Sheridan's finding regarding the relative understandability of the different risk formats as they felt that the ARR information had not been provided appropriately and this had led to less correct answers for ARR .

It is possible that some of our students would have performed better if the readability of the questions had been improved. The concern of inadequate literacy among patients has been raised by Ghosh & Ghosh[2] as well as Sheridan *et al*.[1] Sheridan's ARR statement was found to have a lower readability than the other statements, which might have contributed to it being less well understood[1]. The readability of our questions taken as a whole, was within the generally accepted range (a common requirement for legal documents in many US states is that the readability should be a Grade 9 level or less). Like Sheridan *et al*[1], our ARR statement was more difficult than the generally accepted level of reading (Grade 11.8). Had we reworded the ARR statement to a level Grade 9 or below, more students might have demonstrated competence, especially considering that approximately three quarters of them were non-English mother tongue speakers. Like Sheridan *et al*[1] we question the relative amounts that understandability and numeracy problems contribute to the difficulties found with interpreting the risk formats. We found no link between rational medicine choice, using the different risk formats, and proportional reasoning skills. We believe that the biggest barrier may be not the reformatting of the numbers but reformatting of the language in which the information is presented. Speaking English at home was a predictor of making rational choice in our study.

Statements similar to our questions are likely to be commonly encountered in scientific journals and company literature, which would be sources of information in practice. So, in order to know how best to help students understand these, it would be interesting to determine the relationship between their understanding and their level of literacy in English.

A direct comparison between competences in the initial assessment and the reassessment is not possible because neither the questions nor the exact students were the same. In addition, the percentage responding correctly to the initial question were misleadingly high as, on investigation, those who had

got the right answer appeared to have done so by chance. However, the number of students making a rational treatment selection choice did approximately double indicating that the training was of value. Also, although they were only four, none of the very best students who succeeded in all the reassessment questions had chosen rationally in the initial assessment, so it appears that they must have learned during the training.

However in the end, of the total group of 231 students only 98 (42%) got one or more of the questions right and only 60 (26%) were able to choose rationally. This was despite the fact that the risk information was presented as an events rate chart, a format previously shown to improve patient understanding.[24] As a result there is clearly a great deal of room for improvement, and the literature points towards some promising training innovations that might be associated with success.

Recommendations:

For some years there has been a lack of consensus about the most appropriate risk format for conveying health information.[14] Carling *et al* [9], in an attempt to see how people could make decisions consistent with their own values, have recommended the use of natural frequencies. Absolute risk and the ARR for a treatment could be expressed as a natural frequency as follows: "Treatment results in a drop from 41 out of 1000 to 27 out of 1000 people having a heart attack". Natural frequencies identify the group of people being targeted, with affected individuals being contextualised within this population. This may be why they reduce misinterpretations significantly.[22] This format has been found to facilitate correct decisions among caregivers and patients especially in diagnostics.[9,22,23] Although, several authors, after unsuccessful studies, have challenged natural frequencies as the optimal method for presenting statistical information[25], it would be interesting to test this method in our students.

Another possibility is that pictograms may support learning among these students. Test graphics and other visual displays are being used more and more in an attempt to increase the understanding of verbal and numerical communication.[22] They have been found to improve understanding[26-29] and decision-making[22,30,]. One promising graphic option, involving pictograms representing affected individuals within a population, has been found to assist American Indian patients. [31] Strategies such as these, that have proved successful in underserved communities, may hold lessons for teaching our students how to understand health risk information and communicate it successfully. Many of their future patients will have poor literacy and numeracy skills. South Africa has consistently scored very poorly in two cross-national assessments of mathematics and science performance.[32,33] For performance in Mathematics and Science, South Africa is ranked eighth out of fifteen African countries and the lowest of 42 participating countries worldwide (21 of which are developing countries). By Grade 6, 29% and 41% of pupils were found to be functionally illiterate and functionally innumerate respectively.[33] Consequently our medical students must be prepared to serve patients with poor numerical skills in a multilingual country while many are also dealing with shortcomings in their own proportional reasoning skills.

Conclusion

Heeding the recommendation for research addressing non English speaking populations and individuals[15], our study lays the foundation for determining and addressing the needs of medical students of a multilingual population. It is hoped that this will be a first step in narrowing the gap between the risk interpretation, communication and rational decision-making skills for students.

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CHAPTER 7 DESCRIBING THE LINGUISTIC SKILLS AND CHALLENGES STUDENTS DEMONSTRATE DURING DRUG DOSING PRACTICES

Research Question 7

What linguistic skills and challenges do students demonstrate during drug dosage practices?

This chapter describes the findings that answer the fifth research question. Tables 7.2 – 7.5 at the end of the chapter present a summary of these results.

7.1 Proportion of English home language students for each cycle

At the first assessment of dosage calculations with the first set of 364 students, having a mother tongue that is other than the language of instruction (English) was found to be a predictor for lack of success (Relative risk 1.2; 95% confidence interval 1.1-1.4; 86% *vs*. 70%). In that group 51% spoke English as a home language. However, in the classes that followed, this proportion decreased to 26% and 23% for the class of 262 students involved in the guidelines and dosage equipment trial, and the class of 256 assessed for treatment risk interpretation respectively.

7.2. Association between home language and lack of success

Not being an English mother tongue speaker was associated with failure to develop dosage competence by the end of a year of dosage calculation tuition ($\chi^2 = 20.64$, $p = 0.000005540$; 73.5% *vs*. 50.3%). (Cycle I). It also predicted failure to retrieve dosage information to calculate and prepare doses ($\chi^2 = 65.64$; $p < 10^{-7}$; 83.5% *vs*. 28.6%) (Cycle II). Likewise, it was associated with an inability to perform basic proportional reasoning problems ($\chi^2 = 15.6$; $p = 0.00007843$; 53.2% *vs*. 23.2%) However, there were some notable exceptions where the disparity caused by home language was mitigated or where this factor did not predict lack of success:

7.3 Effect of small group same home language peer learning

The tutorial offered to the group of 364 students in their second year of dosage tuition gave them the opportunity to work through dosage calculation in small groups, where they were able to discuss the problem together with a peer with the same home language. When students were assessed after this intervention, the risk factor of not having English as a home language, present at the start of the study and at the end of the first year of tuition, no longer predicted dosage calculation competence (39% *vs*. 30%; relative risk 1.3; 95% confidence interval 1-1.7). This is described in Paper 2.

7.4 The effect of graphical comparison

With regard to the graphical comparison, of the 17 students who were categorised as having crossed the threshold to reasoning proportionately, 14 spoke a home language other than English. There was no significant difference in the proportion of students succeeding who were not English home language speakers, compared with those successful in the English home language group. There was also no significant difference according to home language for students deemed to be at the liminal stage of reasoning about this graphical information.

The proportions of students coded within the different threshold categories and according to home language are compared in Table 7.1.

Table 7.1 Level of threshold category success of students according to home language

Proportional Reasoning Threshold Category	Home language other than English	English home language	Relative Risk	Confidence Interval	Mid P
PreA	28%	8%	4.0	(1.2-11.5)	0.004523
Preliminal	39%	60%	0.6	(0.5-0.9)	0.01810
Liminal	23%	25%	0.9	(0.5-1.70)	0.7803
Threshold	10%	7%	1.4	(0.4-4.6)	0.6292

The lower proportional reasoning categories did show some differences with significantly more students without English as a mother tongue falling in the lowest category, and more of those who spoke English at home falling into the Preliminal Category. However, when viewed as a whole, approximately two thirds of both groups fell into the lowest two threshold categories, with a third of each making it to the liminal or threshold levels of competence. The readability of the assessment question text received a college level averaging 42.8. The caption for the graph scored Flesch reading ease score of 14, within an even more difficult reading level.

7.5 Linguistic difficulties for both home language groups

Although for most assessments students not having English as a home language were shown to be at more of a disadvantage, deficits in linguistic skills were also evident for English mother tongue speakers. During Cycle II, they answered questions requiring retrieval of dosage information from guidelines incorrectly twice as often as they did questions involving numeric information embedded in a typical paper problem (relative risk 2.2; 95% CI 1.0008-4.9970; 42.3% *vs*. 18.9%). The reading demands made on the student groups retrieving embedded information was greater because the treatment guidelines excerpt that they were required to read and understand received a Flesch reading ease score of 41.5 (College level). The accompanying paper problem for these students scored 63 (8^{th} to 9^{th} Grades). In comparison, the students randomised to the groups who were not required to retrieve embedded information had only to read paper problems, which scored Flesch reading ease scores of 78.2 and 84.7, Grade 7 and Grades8-9 respectively for the typical question and the question provided together with a labelled formulation and syringe. For students retrieving information embedded in guidelines, the use of equipment to calculate and prepare a dose assisted both home language groups when compared with calculation success using only guidelines (relative risk 2.5; 95% CI 1.0588-6.1049; 25% *vs*. 10%).

When students compared two graphical event rates qualitatively, seven of the forty English speaking students were not able to articulate their understanding of the change in risk in absolute or relative terms. Surprisingly, for the proportion of students whose absolute or relative reasoning was inadequately articulated, there was no significant difference between English speaking students and those with other home languages (relative risk 1.8; CI 0.8-4.2; 17.5% *vs*. 9.6%).

7.6 The effect of home language on the ability to work with treatment risk statistics

When students interpreted a treatment chart to choose an appropriate statement involving treatment risk statistics, having a home language other than English caused students to be twice as likely to respond incorrectly or not answer the question involving relative risk and relative risk reduction (relative risk 2.0; 95% CI 1.47-2.78; 85%. *vs*. 42%; $n = 231$). This association remained when only the students who answered the question were included (relative risk 2.3; 95% CI 1.5-3.7; 71% *vs*. 30%; $n = 139$). However, for the question involving absolute risk and the Number Needed to Treat (NNT), there was no significant difference related to home language, with the proportions incorrect or unanswered for students speaking other home languages, and English mother tongue speakers being equally poor (relative risk 1.1; 95% CI 0.98-1.2; 96% *vs*. 89%; $n = 231$). The lack of significance remains when only the students who answered the question are included (relative risk 1.0; 95% CI 0.9-1.3; 89% *vs*. 82%; $n = 97$).

When students interpreted treatment risk statistics to make a rational treatment choice, a mother tongue that was not English again predicted an irrational choice (relative risk 1.4;95% confidence interval 1.1-1.7; 79.6 *vs*. 58.2%; $n = 231$). When only the students who tried the question are included, the association remains (relative risk 1.6; 95% confidence interval 1.1-2.3; 70% *vs*. 44%; $n = 161$.)

For both of the results table questions, the readability was similar, with the most difficult sentence for each question scoring a Flesch reading ease score of 67.9. Likewise, the rational treatment choice question scored 66.7. Scores between 60 and 70 are at the level considered to be understood by students with a grade 8 or 9 level of education who are reading it in their home language.

7.7 Readability of Assessment items

The findings of the readability analyses conducted for the different cycles is summaris ed in the Research Summary (Table 7.2).

7.7.1 Readability shortcomings

This characteristic has been measured using only one of several different measures of Readability, and only considers this very superficially. The Flesch measure is based on the premise that longer words

and longer sentences are harder to read. However, this is not the only reason behind language comprehension problems, particularly for students reading a language that is not their mother tongue. This measure does not account for the difficulty caused by unfamiliar short words for example. Conversely, although long with many syllables, medical terms such as 'cardiovascular' would be familiar to medical students and not cause them any difficulty (Ferguson & Maclean, 1991). In order to fully understand the relationship between readability and the drug dosage practices students are able to show, this would need to be considered more carefully than the scope of this study allowed.

Table 7.2 Research summary part 1

What **linguistic** skills and challenges do students demonstrate during drug dosage practices?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Quantitative Retrospective analyis	Researcher compared the proportion of students whose home language was English, the language of instruction for each cycle	Cycle I 3rd→4th year students (n = 364) Cycle II 1st year students (n = 239) Cycle III 1st→2nd year students (n = 256)	% English home language speakers: Cycle I 51% ↓ fell to 26% (Cycle II) & 23% (Cycle III)
Quantitative Retrospective analysis	Researchers determined drug dose practice assessments for which a home language other than English predicted a lack of success		Lack of success Other English Typical dosage calculations: *Cycle I* Initial assessment*# 86% 70% After a year of tuition 73% 50% Dosage calculation*** and preparation of dose: *Cycle II* Non-embedded format 72% 19% Embedded format 94% 42% Basic proportional reasoning problems *Cycle III* 53% 23% Same conclusion for risk described three different ways 80% 58% Interpretation of treatment chart: Relative risk 85% 42% Rational choice****## 80% 58%

* Included in Paper 1#

*** Included in Paper 3

although relative risk and 95% CI is reported, the proportions for each group are not

although reported as a predictor , the proportions for each group are not reported

Table 7.3 Research summary part 2

What **linguistic** skills and challenges do students demonstrate during drug dosage practices?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Quantitative Retrospective analyisi	Researchers determined drug dose practices where the home language factor was not associated with success	Cycle I 3rd→4th year students (n = 364) Cycle III 1st→2nd year students (n = 256)	Lack of success *Cycle I* English Other End of 4th year ** after group tuition 39% 30% **Mitigation of home language disparity by time &practice, peer learning tuition & individual tuition for struggling students** *Cycle III* Qualitative graphical comparison: Success English Other Crossed Threshold 7% 10% Liminal space 25% 23% 32% 33% Two thirds of both linguistic groups did not succeed past preliminal stage Interpretation of treatment chart Lack of success Other English Absolute risk/NNT 96% 89% **Both groups have proportional reasoning, graphical literacy or conceptual deficits or they have linguistic deficits that do not allow them to demonstrate these abilities**

** Included in Paper 2

although reported that home language was lost as a predictor by the end, the percentage success per group is not reported

Table 7.4 Research summary part 3

What **linguistic** skills and challenges do students demonstrate during drug dosage practices?

Research type	**Task undertaken by the students or researchers**	**Sample academic level (n)**	**Contribution to the understanding/resolution of the problem**
Quantitative Retrospective analysis	Researchers determined the drug dose practice assessments where students with English as a home language also showed language deficits	Cycle I 3rd→4th year students (n = 364) Cycle II 1st year students (n = 239) Cycle III 1st→2nd year students (n = 256)	% English home language students unsuccessful rose from 19% when retrieving numerical information from a paper problem to 42% when retrieving from guidelines*** In the qualitative graphical comparison, there was no statistically significant difference between English speaking students *vs.* students speaking other home languages (18% *vs.* 10%) who could not articulate their understanding of how the two graphs differed **Linguistic challenges not fully accounted for by home language differing from language of instruction**

*** Included in Paper 3

Table 7.5 Research summary quantitative

What **linguistic** skills and challenges do students demonstrate during drug dosage practices?

Research type	**Task undertaken by researchers**	**Sample academic level (n)**	**Contribution to the understanding /resolution of the problem**
Quantitative Readability assessment	Researcher assessed the difficulty of the literacy task by determining and comparing the readability of the different assessments according to the Flesch reading ease score	Cycle I 3rd→4th year students (n = 364) Cycle II 1st year students (n = 239) Cycle III 1st→2nd year students (n = 256)	**Less readable assessments were sometimes more difficult:** *Cycle II* When requiring guidelines even for English home language students (42% wrong with guidelines *vs.* 19% without) Flesch reading Ease score / Readability level Guidelines 41.5 College *vs.* Typical 78.2 Grade 7 *vs.* with equipment 84.7 Grade 8,9 For other home languages there was less difference, suggesting difficulty interpreting both readability levels (94% wrong with guideliness *vs.*72% without) *Cycle III* Graphical comparison Flesch reading Ease score / Readability level Question 42.8 College Graph caption 14 College graduate All students struggled irrespective of home language **Questions were sometimes difficult despite good readability:** *Cycle III* Although scoring at the Grade8,9 readability level, the results table interpretation and rational drug selection questions were difficult for students (< 50% successful) **Suggesting linguistic challenges not the only challenge for students**

CHAPTER 8 TAKING STOCK OF DOSAGE PRACTICE SKILLS AFTER THREE DEVELOPMENT CYCLES OF A QUANTITATIVE LITERACY COURSE

Research Question 6

What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?

This chapter presents the results of the aspects of the research answering Research Question 6. At the end of the chapter a summary of this research is provided in Table 8.5.

The different tuition and assessments for students in Cycle III, the measure of the success of the assessment, and the time when they were administered after the start of the students' first year of study (for the first three semesters), is shown in Table 8.1.

Table 8.1 Timeline for the quantitative literacy programme administered in Cycle III

Time from start	Tuition/Assessment type	Outcome measures
0 months	Proportional reasoning skills assessment	% students answering all of three proportional reasoning questions correctly
0-6 months	New dosage calculation tuition	
9 months	Asked to make a treatment decision based on treatment statistics	% students making the same treatment decision for three scenarios: each describing treatment risk using a different risk statistic (relative risk, absolute risk and the number needed to treat or NNT)
	Qualitative evaluation of two treatment risks presented as a graph	% students classified as crossing the threshold to reasoning proportionately when comparing two treatment risks described graphically
9-13 months	Training in interpreting treatment risk statistics	
12 months	Dosage calculation assessment of typical questions	% students answering at least one each of four dosage calculation question types correctly
	Dosage calculation assessment extracting dosage information from guidelines	% students answering all four questions correctly for each of two cases which each required retrieving numerical information embedded in an excerpt from a different set of guidelines
18 months	Assessment of ability to use a results chart presenting treatment risk statistics: relative risk and absolute risk	% students choosing the correct statement describing the relative risk and % students choosing the correct statement describing absolute risk
18 months	Assessment of the ability to make a rational treatment choice	% students choosing the most effective treatment from four options, when given three statements, each describing the risk of a different treatment option using a different risk statistic: relative risk, absolute risk and the number needed to treat

8.1 Drug dosage comparisons

In the third cycle not all the students in the class took part in the formal assessment from which the dosage calculation information was gathered (the final end of module examination) because some students had received an exemption due to high achievement in the end of term assessment. However, because the more able students were not included, the competence achieved was expected to have been lower than would have been achieved had the whole class been included in the study. Also, the competence of the students in the first cycle was a cumulative score over two years. It would have been a more comparable measure to compare the competence achieved cumulatively when students in the third cycle were assessed several times over two years to the students in the first cycle. Still, students managed to achieve the same level of competence in one assessment (though with double the questions so double the opportunities to be successful in each question type) after only one year of tuition. This suggests that, if the student groups in the different cycles are reasonably comparable, then the curriculum changes have assisted an equivalent proportion of students reach competence in half the time. In fact, the proportion of students having a home language other than English had increased between Cycle II and Cycle III. As this was a risk factor predicting lack of success at calculating drug dosages at one year, the fact that the same proportion of students attained competence points to an improvement due to the curriculum changes.

Although the results in terms of success for the calculations requiring retrieval of dosage information from guidelines appear equivalent, students in Cycle III were given two scenarios, each involving one patient and set of guidelines and each with four questions. In order to be deemed successful, they had to retrieve information from two sets of guidelines and answer eight questions correctly compared with one question and set of guidelines for the 60 students from Cycle III answering retrieving embedded information. When the number of correct answers are compared with the number of opportunities, the students in Cycle III answered correctly 47% of the time (ie scored an average of 47%) As students in Cycle III had two scenarios, each involving one patient, the 127 students could each be considered to have treated two potential 'patients', 254 patients in all. Altogether 76% of these 'patients' received the incorrect dose at least once, and consequently 24% received the correct dose every time.

The outcomes of the assessments are shown in Table 8.2, and compared, where applicable with similar assessments in previous cycles.

Table 8.2 Success shown by students in Cycle III compared with previous cycles

Stage in tuition	Skill type	n in Cycle III 256 in all	Success Cycle III	Success in previous cycles
0 months	Paper proportional reasoning problems	247	55%	Not assessed
9 months	Treatment decision based on treatment statistics	157	20%	Not assessed
	Qualitative evaluation of two treatment risks presented as a graph	175	10%	Not assessed
12 months	Drug dosage calculations: typical questions	127	66% students deemed competent Score for one assessment comprising at least two of each question type (competence was getting one of each correct) 68% 'patients' correctly dosed	66% students deemed competent Cumulative score after an average of three assessments repeated over 2 years, each comprising one of each question type Cycle I (n = 364) 66% patients correctly dosed
	Drug dosage calculations: extracting information from guidelines	127	10% students correct (8 questions, two sets of guidelines) correct dose given 47% of the time 24% of potential 'patients' received the correct dose every time	10% (n = 60) from Cohort 2/Cycle II) % students within one of four randomised groups answering one question correctly. Correct dose given 10% of the time 10% of potential 'patients' received the correct dose
18 months	Assessment of ability to use treatment risk statistics in the form of a results chart: one question on relative risk	231 139 answered	**59 students correct 26%** **42%**	Not assessed
	Assessment of ability to use treatment risk statistics in the form of a results chart: question on absolute risk	231 97 answered	**13 students correct 6%** **13%**	Not assessed
	Assessment of ability to make a rational drug choice	231 161 answered	**60 students correct 26%** **37%**	Not assessed

Table 8.3 compares the demographic characteristics of the three student cohorts that participated in the different cycles

Table 8.3 Demographic characteristics of the three cycles of student cohorts

	Cycle I	Cycle II	Cycle III
	Cohort 1 3rd→4th year students (n = 364)	Cohort 2 1st year students (n = 239)	Cohort 3 1st→2nd year students (n = 256)
Sex	59% female	50% female	58% female
Home language	51% English 27% isiZulu 22%Other (10 languages)	26% English 62% isiZulu 12%Other (9 languages)	23% English 57% isiZulu 20% Other (8 languages)
South African school leaving examination	92% wrote the examination	90%wrote the examination	97%wrote the examination
Average school leaving score	44 of possible 50	40 of possible 48	39 of possible 48

Although the results in terms of success for the calculations requiring retrieval of dosage information from guidelines appear equivalent, students in Cycle III were given two scenarios, each involving one patient and set of guidelines and each with four questions. In order to be deemed successful, they had to retrieve information from two sets of guidelines and answer eight questions correctly compared with one question and set of guidelines for the 60 students from Cycle II answering retrieving embedded information. When the number of correct answers are compared with the number of opportunities, the students in Cycle III answered correctly 47% of the time (i.e. scored an average of 47%) As students in Cycle III had two scenarios, each involving one patient, the 127 students could each be considered to have treated two potential 'patients', 254 patients in all. Altogether 76% of these 'patients' received the incorrect dose at least once, and consequently 24% received the correct dose every time. The readability and mathematical difficulty of the calculations for these cycles is compared in Table 8.4.

Table 8.4 Difficulty of questions involving retrieval from guidelines (Cycles III & II)

Drug	Readability		Proportional reasoning level	Other arithmetic aspects that add to difficulty level	Question format
	guidelines	questions			
Cycle III: Insulin	42.1 College	60.7 8th,9th grade	Similar	Units not mL, decimal fractions unit/kg dose daily dose divided 2/3 am &1/3pm	Matching
Cycle III co-trimoxazole	30.1 College	42.7 College	Similar	Solution of two drugs	Matching
Cycle II Digoxin	49.5 College	63 8-9th grade	Similar	Decimal fraction mg/kg dose and decimal fraction formulation mg/kg/day in two divided doses	Fill in the blank

8.2 Shortcomings

8.2.1. Timing of the final assessment

It would have been optimal to follow the students in Cycle III for a longer duration, at least throughout their second year. Then dosage calculation competence could have been assessed to see if a greater proportion or, ideally, all students would attain competence. This would also have allowed opportunities for additional assessments of dosage calculations involving dosage information embedded in guidelines, risk interpretation and rational drug selection to see whether, like dosage calculation skills, competence improved with time and practice, with opportunities for small group discussions of tutorials and with individualised tuition for struggling students.

8.2.2. Lack of assessment of dosage preparation

An additional shortcoming was that the skill of measuring a prepared dose in a syringe was not assessed in this cycle, nor was dosage equipment supplied to students during the assessment of dosage calculation involving retrieval of dosage information from guidelines.

It must be remembered that different cohorts of students are being followed so that a direct comparison cannot be made. However, it is possible, even at the stage in the students' development, to see that the curriculum changes seem to be assisting students to reach a similar level of dosage competence in a shorter time, allowing an opportunity for tuition to extend to additional important dosage practices.

The level of success students have shown represents a minimum level of ability, as teaching was ongoing and they were given other opportunities to build on these skills in their preclinical years.

Table 8.5 Research summary

What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?

Research type: Action research **Task undertaken by the students:**	**Success attained by last assessment for each sample academic level (n)** (with cross-referencing sections giving rationale for/description/discussion of measure of success)			**Contribution to the understanding/resolution of the problem**	
	Cycle I **3rd→4th year students** **(*n* = 364)**	**Cycle II** **1st year students** **(*n* = 239)**	**Cycle III** **1st→2nd year students** **(*n* = 256)**	**Which Research Question (RQ) addressed**	**Shortcomings**
Typical dosage calculations	At 2 years* & ** 66% competent 66% receiving correct treatment **Section2.6.1.2.2** **Section 4.1.1**		At 1 year 66% competent 68% receiving correct treatment **Section2.6.4.6.1** ∧ **Section 6.5**5	**RQ 2** benefit of teaching materials **RQ 6** Cycle III students showed similar skills in a shorter time **Section 8.1**	not tracked, not measured at 2 years
Calculations needing dosage information retrieval	not assessed	10 hrs tuition*** 10% success 10% correct treatment (25% success with equipment) **Section 2.6.3.3.2** **Section 5.1**	10 hrs tuition (6 months later) 10% success 24% correct treatment **Section 2.6.4.6.2** **Section 6.5**	**RQ2** benefit of equipment, role of linguistic difficulty **RQ5** role of readability, linguistic difficulty **RQ 6** Cycle III showed similar skills, and also retention of skills **Section 8.**	baseline only no tracking development in stages role of equipment not measured in Cycle III
Prepare dose in syringe	not assessed	*n* = 118*** 36% correct 28% drew up the volume they had calculated **Section 2.6.3.3.2** **Section 5.1**	not assessed	**RQ 3 & 6** *unexpected finding* has led to new tuition	shortcoming skill not measured in Cycle III
Making qualitative graphical comparison	not assessed	not assessed	assessed at start 10% correct in relative terms 11% correct in absolute terms **Section 2.6.4.5.2** **Section 6.4**	**RQ 4 & 6** provides a baseline to evaluate future curriculum interventions	baseline only no stages
Interpret chart to calculate relative & absolute risk	not assessed	not assessed	*n* = 231**** 26% correct 6% correct **Section 2.6.4.7** **Section 6.6.2**		baseline only no stages
Select rational treatment	not assessed	not assessed	*n* = 231**** 26% correct 74% patients potentially harmed **Section 2.6.4.7** **Section 6.6.2**		baseline and follow up but sampling and confounding issues)

* Included in Paper 1 ** Included in Paper 2 *** Included in Paper 3 **** Included in Paper 4

CHAPTER 9 SYNTHESIS

9.1 Resolution of the research questions

In an earlier study assessing a therapeutics programme for medical students at UKZN, provided at their request, dosage calculation was found to be the poorest key prescribing competence. (Botha et al., 2006). Consequently, when a study by Simpson et al. published the set of calculations involving common acute clinical scenarios they had used to test hospital clinicians, the researchers decided to assess the ability of UKZN students (Simpson et al., 2009). This was the impetus that began the line of enquiry for this study and led to the development of a quantitative literacy programme for drug dosage practices.

The **first research questions** was 'How successful are medical students in dosage calculations at the start of training?' Dosage training was provided and students were tested using some of the Simpson questions in the study of Simpson et al., slightly adapted to suit local medicine formulations and dosage guidelines. The questions were grouped according to the way concentration was formatted, as the study by Simpson and colleagues reported different success between the different calculation types, and one of each of the three concentration formats was included in the assessment, together with a drip rate calculation question type (Simpson et al., 2009). When few students got all four questions correct, and some responded with wildly inappropriate volumes, it was decided to track students over the course of their third year with further assessments included in formal assessments, offering feedback and further revision sessions**.** Success rose by the end of the year, but some students still had very poor results and written responses showed the processing revealed by student responses was sometimes still unfathomable.

Consequently, the **second research question,** 'What interventions improve medical students' success?' was formulated. Two samples of students, a stratified group with unfathomable errors, and those with the weakest results were observed working through the questions they had got wrong. This allowed difficulties to be revealed, and identified teaching strategies that assisted students. It was decided to continue tracking students the following year, offering a further opportunity for tuition, assessment and the opportunity to show that dosing competence had developed. The consecutive third year class started, receiving the same programme and same intervention and assessment opportunities (formal assessments, observed interviews and fourth year small group tuition). The two classes were pooled to decrease any effect peculiar to a particular class in a particular year, considered to be one cohort (**Cohort 1**, n = 364) and analysed as a whole, comprising **Cycle I** of the study. The quantitative parts of study answering this research question and question one forms the content of Papers 1 and 2. **Paper 1** quantifies student competence at the start (**23%** students competent) and cumulatively by the end of their two years of tuition after they had been assessed a variable number of times (**66%** students showed competence in at least one assessment), for all students and then compares the success or partial success of students who showed competence from the start, those who developed competence by the end and

those who did not develop competence. Section 2.6.1.2.2. and 2.6.2.2.2 describes how this attainment of dosage calculation competence is measured).

The different levels of success for different question types is described for students as a whole and for the different groups based on the status of their competence. **Paper 2** tracks the development of competence cumulatively in different stages- at the start, by the end of the first year (**38%** students achieved competence by this stage) and by the end of two years. It also describes the effect of the teaching interventions- extended time for teaching and assessment, individual tuition for students who had not developed competence and the effect of peer tuition, with all of these contributing to overall student success. For the observed individual tuition, **10** of the least successful students and a stratified sample of **13** students improved over 24 months. For the small group tuition with the opportunity for peer learning offered to all students, among the group of **200** students whose uptake was tracked, attendees (n = 83) **improved by 10%**, while non-attendees (n = 117) **became worse by 3%.**

The themes developed in the analysis of the qualitative aspect (unpublished data) informed **curriculum change** and the design of the remaining research questions.

The **third research question**, 'How does broadening a drug dosage practice task to include more workplace **contextual i**nformation change success?' arose after the error analyses conducted on the first cohort of students revealed some students had responded with unrealistically answers, such as big volumes to dose babies. Asking students to both calculate and prepare a drug in a syringe would allow students to be guided by limits provided by the syringe and formulation. In addition, poor calculation success had been found in an earlier paper where students had to retrieve dosage information from a package insert in order to calculate a drug dose. (Harries et al., 2006). As package inserts are textually very dense, the material was switched to the more readable South African Standard Treatment guidelines. Both retrieving dosage information from treatment guidelines and formularies and preparing a dose in a syringe are tasks that often form part of the practice of dosing a drug in the workplace. Broadening dosage calculation assessment to include this contextual information was expected to align classroom skills taught with tasks as they are encountered in the workplace. The goal was to prepare students with the necessary competences and to facilitate transfer of skills.so they would be accessible in the clinical years.

As the students from Cohort I had moved on to their clinical placements and with the development of the new Foundation Phase in the first year, a new class, this time of first year students (**Cohort II,** n = 239) was selected for this randomised controlled study comprised of four arms, with students in each arm performing a different mix of drug tasks. Group 1 was given numerical dosage information and calculated a dose (**43%** success), Group 2 extracted dosage information from guidelines and calculated

a dose (**10%** success), for Group 3 the intervention was as for Group 1 but they also prepared the dose required using a bottle of formulation and a syringe (**46%** success) and for Group 4 conditions were as for Group 2 but these students also prepared the calculated dose using the formulation and syringe (**25%** success).

The linguistically challenging task of retrieving a drug dosage was significantly more difficult for students. Though drawing up the dose calculated from a bottle of the 'formulation' (in fact tea) in a syringe did not result in significantly improved results compared with students who only had to write down the volume of medicine required, it did assist students asked first to retrieve numerical information from the guideline excerpts to succeed. Unexpectedly, 22% of students were not able to measure the dose they had calculated to prepare a dose and this may have contributed to the lack of significance between students using dosage equipment and those who are not. This work is described in **Paper 3.**

In answering the **fourth research question,** 'What **proportional reasoning** skills do students demonstrate during drug dosage practices of increasing difficulty?', a third class of students (Cohort III, n = 256) were tested with a range of assessments. The focus of the tasks involved in drug dosage practice was broadened to include the task that in practice precedes dosage calculation: choosing the treatment to be given. This involves interpretation of treatment risk statistics to make a rational treatment selection. These tasks involved more elaborate proportional reasoning compared with calculating a drug dose. It also required higher level cognitive skills. The ability to reason proportionately is a threshold skill to critical thinking, a competence that is a goal for university students. For the different tests, convenience samples of students were drawn from the original class. These were the students present for a particular lecture or examination when the assessment was undertaken. A basic numeracy test was undertaken in **247** students, with part of this assessment measuring basic proportional reasoning ability in which **55%** of students succeeded. For two formative assessments, first **157** participants, **20%** made the same treatment decision, which might have been rationally motivated, for the same treatment information presented in three different risk formats. Then, **175** students were asked to compare two graphical representations of treatment risk rates, relating the size of one rate to the other qualitatively. This task was considered to be more of a measure of students' proportional reasoning ability than calculating a relative or absolute risk, where students might resort to procedural computing using an algorithm and get the answer right, without actually reasoning proportionately. The map that was developed staging student responses according to where they were in relation to crossing the threshold to reasoning proportionately showed that **10%** demonstrated skills showing they had crossed the threshold to dosage competence. Students then received formative assessment feedback and a lecture.

Formal assessments followed the next year, assessing ability to use treatment risk statistics in the form of a results chart (with one question on relative risk and one question on absolute risk) and to make a rational treatment decision. Students who participated in these assessments (n = 231) struggled with both the assessments involving the treatment chart (with **26%** and **6%** showing success) as well as with making a rational treatment choice (with **26%** successful). As many students did not attempt these questions, perhaps due to time constraints or negative marking, the students who answered correctly as a percentage of those who attempted the question was also calculated. For the treatment chart, **42%** were correct of **139** students answering the relative risk question and **13%** of **97** students answered the absolute risk question correctly. For the treatment choice, **37%** answered rationally (n = 161).

The numeracy assessment, the formative treatment choice assessment, and the formal assessments of the ability to use treatment risk statistics are described in Paper 4. The second formative assessment (the treatment rate comparison and proportional reasoning threshold competence analysis) is currently unpublished and described in Section 6.4 Also unpublished are the formal dosage calculation assessments which were conducted after training (described in 6.5). These were used to compare the success for different dosing tasks, with students faring better for typical dosage calculations in the end of year examination (n = 127, **66%** success) than for extraction of dosage information from guidelines (n = 127, **10%** success) and the more difficult risk interpretation tasks which required more complicated proportional reasoning (for which results are described in the previous paragraph). Tables of the assessments answering the fourth research question, their results and implications can be found in Section 6.6 (Tables 6.4 and 6.5). For a timeline of the stage in tuition when the students participated in the different assessments, see Table 2.1 in the Methodology chapter and for a timeline and comparison of Cycle III with other cycles see Table 8.2 in Section 8.1.

The **fifth research question**, 'What **linguistic** skills and challenges do students demonstrate during drug dosage practices?' was informed by reflection on **all four papers** and in some cases reanalysing responses and material for associations between success and home language. The percentage of students having English as a home language fell from 51% in Cohort I to 26% and 23% in Cohorts II and III respectively. For most drug dose practice assessments, a home language other than English predicted a lack of success. These included, in Cohort I, competence in initial typical dosage calculations and cumulative competence after one year; in Cohort II, calculating and preparing a drug dose to be administered; and in Cohort III, basic proportional reasoning, both formative and formal rational drug selection assessments, and interpretation of a treatment chart to work out relative risk .Encouragingly, home language was lost as a predictor of dosage calculation competence by the end of the second year in Cycle 1, after small group tutorials allowing for same-language peer learning.

Interestingly, home language was not associated with success for the graphical comparison formative assessment. In fact, 10% of students with other home languages demonstrated they had crossed the threshold to reasoning proportionately, while 7% of English home language students were deemed to have crossed the threshold. Two thirds of both linguistic groups did not proceed past the preliminal stage toward reasoning proportionately. The College level readability rating for this assessment may have been difficult for both home language groups to understand.

Again, in the question involving the interpretation of the results chart, for the absolute risk question, results between language groups were equally poor (96% incorrect for home language other than English and 89% incorrect for English home language). The readability was rated at a Grade 8 to 9 level.

These findings suggest that both groups either have mathematical difficulties with proportional reasoning or making sense of a graph and risk statistics, or that they have linguistic deficits that hamper their ability to demonstrate their understanding. The fact that students struggled with the treatment chart absolute risk question, despite it being rated at a level considered to make it Plain English (clear and concise language) suggests that linguistic challenges are not the only challenge for students and that there are also mathematical challenges.

Also, home language did not explain all the linguistic difficulties encountered. In Cycle II, English home language students were twice as bad at calculations involving retrieving embedded dosage information from guidelines than from typical paper problems, suggesting difficulties with the college level readability of the excerpt and question when compared with the paper problem where the readability was within the range deemed to be Plain English. For other home languages there was less difference, suggesting difficulty interpreting both readability levels.

The **final research question**, 'What drug dosage practice skills do medical students show after three developmental cycles of a quantitative literacy course?' was informed by reflection **on all four papers** and by comparing the results found in the three cycles with each other to see whether there was any evidence for improvement as a result of curriculum developments and teaching interventions. In particular, the unpublished formal dosage calculation findings (discussed in research question 4) were used to compare success between cycles.

For the typical dosage calculations, competence was calculated to be 66% by the last assessment for Cycles I and III. The other measure of dosage ability, the 'percentage of potential patients that would have been correctly treated' was also similar. The samples are not similar because the whole population of Cohort 1 was assessed in Cycle I, whereas the better students were exempt from the final examination

in Cycle III, so , if success in the main medical school assessment predicts dosage calculation success, the ability of students assessed in Cycle III might have been expected to have been poorer. Also, while the other demographic characteristics of the groups are reasonably similar, there was a lower proportion of English home language speakers in Cycle III. As not having English as a home language predicted a lack of dosage calculation competence initially and after a year of tuition, this difference would be expected to result in a poorer competence for the group in Cycle III than would have been the case if the proportion of English home language speakers were similar between the two cohorts. In addition, the competence calculated in Cycle I is cumulative, while the competence in Cycle III was for a single test, but because the larger number of questions in the Cycle 3 assessment provided similar opportunities to attain competence, the assessments are considered to be comparable. Finally, the assessment in Cycle I was measured after two years, whereas the Cycle III measure was at 1year.The fact that despite these differences, competence for Cycle III is similar to Cycle I, indicates that the curriculum changes are improving student learning.

For the dosage calculations requiring retrieval of dosage information from guidelines, 10% of students calculated correctly among the randomised arm of 60 students assigned to answer a question of this type. Similarly, in Cycle 3, 10% of students correctly answered the four questions for each of two fictitious cases. Regarding the comparability of the sampling: because the sample in Cycle II had been randomly assigned, it could be considered to be representative of Cohort 2. The sample in Cycle III, as previously discussed, would have been expected to show less dosage competence because the most academically capable students had been granted exemption from writing the formal examination and were not part of this sample. The home language status of the two cohorts was similar. Regarding the comparability of the assessments, the overall readability of the questions was easier for Cycle II, because one of the questions in the Cycle III assessment was given a college level rating while the other question and the cycle II questions fell within the Plain English range. Despite these differences, the sample in Cycle III was able to show comparable competence. If competence was instead measured as the percentage of potential patients who received correct medicine, then the students sampled in Cycle III would show an improved competence of 24% compared with 10% in the earlier cohort. These findings, while keeping in mind the differences in sample and assessment, and while the effect size is small and there is a long way to go to reach the goal of all students being able to demonstrate dosage calculation competence, do suggest a benefit to students from curriculum changes.

9.2 Reflection on aspects of study design and limitations

The benefit of a longitudinal study is that it shows patterns of a variable over time and helps to identify causes for these changes. This research lent itself to including a longitudinal aspect because of the large class sizes and regular scheduled face-to-face contact which caused students to be accessible for recruitment. Students were willing to provide their written consent, as the research being undertaken

involved evaluating the scheduled teaching/learning interactions in the academic programme and was expected to benefit their learning. Questions in formal assessments meant they were not inconvenienced by additional testing. The researcher was in contact with the students over different semesters during the three preclinical years as therapeutics large group sessions related to different themes are scheduled throughout the preclinical years. and this allowed for students to be tracked. Demographic factors of interest such as home language status were readily available from faculty and others, such as the school quintile used as a marker of socioeconomic status could be obtained from the university with written permission. Logistical difficulties included accessing students once they moved on to the clinical years for intervention and assessment, arranging for the dosage calculation question types to be included in student formal assessment and laborious data capture from student response sheets which was only available in a raw form and had to be manually entered into a spreadsheet, so that for every student in the cohort there was a data entry for their response to each assessment question. The longitudinal lens allowed students' development in dosage competence to be seen in stages, and the impact of different teaching interventions to be viewed.

In order to sample students' ability at different stages and track growth the measure of dosage calculation competence was developed which overcame the dilemma of the need to use different test questions in the different student assessments for academic rigour, but also requiring questions to be comparable so that a change in success was attributable to student improvement and not to differences in question difficulty. An additional interesting measure of competence which has been used in this study and deserves further attention is the measure of 'percentage potential patients harmed'. This could be used to track students as they move through the preclinical years, hopefully achieving and retaining a score of zero. This measure allows test questions with different designs to be compared if they involve treatment of a patient. It could also be used as a common measure of competence to give some idea of how this compares for different aspects of drug dose practice. It keeps the goal focused on avoiding potential harm. To avoid potential harm all the steps must be conducted correctly, so that patients will be offered rationally selected treatments retrieved from guidelines in the appropriate dose, prepared and administered correctly.

It must be remembered that the classes of students that formed the cohorts that were followed, though they were the entire class, were a convenience sample and not representative of students in general. This is a limitation of action research generally, but as the purpose in teaching action research is curriculum development for individual cohorts of students and those that follow, the generalisability of the results is of less concern than the evidence of the impact of teaching interventions for the students being taught and those to come.

In Cycle III, the students participating in the different cross-sectional studies were convenience samples- the students who attended the session or who were eligible for the formal assessment. As they are not randomised, findings are not representative for the whole group. As such they must be interpreted with caution.

In action research, data gathered is analysed as far as possible as soon as it is collected or at least ideally by the end of each cycle. A limitation of this study is that, although the researcher was observing while teaching, collating data and getting a gist of emerging patterns on an ongoing basis, because of the time-consuming data collection process and ongoing teaching demands, data for cycles two and three were only analysed at the end of cycle three If the analysis had proceeded more timeously and before the start of a new cycle, additional interventions could have been included, such as an assessment of students' ability to prepare a dose in a syringe before and after tuition. As discussed Chapter 8, the task of preparing a dose in a syringe, was not assessed, despite the unexpected finding in Cycle II in more than a fifth of students that students were unable to draw up the dose they had calculated in a syringe even though the dose they calculated was small enough to be drawn up in the syringe provided. This is a study shortcoming and should be a future area of research.

A further shortcoming is that Cycle III should have continued for two years to allow for more meaningful comparisons between the Cycles, particularly Cycle I (discussed in Chapter 8), and that students should have been followed longitudinally with staged measuring of dosage retrieval, graph interpretation, chart interpretation over time, and treatment selection, by including repeated assessments along the lines of Cycle I. Although an assessment for drug selection is repeated, study sample differences and confounding in the assessment design (discussed in Chapter 6) meant they were not sufficiently comparable to measure student improvement optimally. Ideally students' graphical qualitative interpretation of statistics would have been measured after they had attended the feedback session. In that session they were provided with contextual information about randomised controlled trials and shown how such a graph could be used to generate the three different risk statements in the first formative assessment. This was the big reveal of the fact that the three risk statements they had based their treatment decisions on in the first formative assessment all described the same risk. They were shown how to generate three similar risk statistics to make statements describing their own graph, in an attempt to also improve more flexible manipulation of the figures into different formats. It would have been invaluable to see whether there was any shift toward reasoning proportionately as a consequence of this lecture, and whether more students were able to achieve threshold proportional reasoning competency. This was not achieved, due to time constraints and logistic reasons, and because the data had not yet been analysed, so the effect of such an intervention will have to be studied another day.

Formal testing of treatment results chart interpretation and rational drug selection did occur but only in the next year. Also, these involve different processes: manipulating risk statistics to compare treatments compared with reasoning qualitatively about a graph. Repeated formal testing of treatment chart interpretation ability and rational treatment selection was also not achieved and this is an opportunity lost. It would have been good to test the teaching interventions (having repeated assessments and teaching over a longer time, peer teaching and individual strategies) that had been found to assist students in Cycle I, this time to see if they had an impact on students' ability to work with risk, as well as on the ability to retrieve dosage information from guidelines. Following students for a longer period in Cycle III would have also allowed for repeated dosage calculation testing and further dosage competence gains may have been made when compared with the other cycles. Despite sampling and assessment differences compared with Cycle I that tended against this, without the extended teaching and other interventions and in a shorter time than Cycle I, students achieved equivalent dosage competence in Cycle III. This is indicative of course improvement due to changed course material in response to observed teaching and interview focused on intensive quantity. This suggests that our focus, in Cycle III, on making explicit the contextual way percentage is used in percentage concentration that is different to the everyday and general mathematic way; on providing more visual information aimed at improving contextual understanding e.g. meaning of vial, ampoule, administration set; and on teaching basic arithmetic skills is helping students.

The nature of action research is that it is ongoing. Reflection on the findings answering one research question suggests others and this has been the case in this study.

9.3 Implications and Recommendations

There is cause for concern regarding medical students' ability to demonstrate workplace skills requiring proportional reasoning in terms of calculating a drug dose, interpreting treatment risk statistics and using these to make a treatment decision. In addition, students experienced difficulty with the related skills of drawing up the required drug volume in a syringe and navigating treatment guidelines to obtain the numerical information required to calculate a drug dose. Students made progress following teaching interventions, and results improved after implementation of teaching changes that were identified when observing the teacher's response to the needs of students during observed individual teaching. (see Papers 1 and 2), However, by the end of the study, a third of students in both Cycles I and III did not develop competence, and for Cycle II, the competence was even lower, with over half of students failing to calculate a dose successfully even in the best group of the four for that cycle.

When typical dosage questions were redesigned to align with the workplace, the increased level of linguistic skills required to retrieve numerical information from detailed guidelines reduced dosage calculation skills success further. Only 10% of students in Cycle II succeeded in calculating a dose when the numerical information required was embedded in an excerpt from treatment guidelines and, again, only 10% in Cycle III were able to fully answer two dosage calculation questions which each required finding numeric information from treatment guideline excerpts. Having a labelled bottle of formulation did make it easier to find the necessary information for students who were given guidelines, improving competence to 25% but this still meant three quarters could not look up the required information in the guidelines or find the concentration on the label of the bottle of 'formulation' and then proceed to calculate a dose successfully (see Paper 3). When the workplace skill was changed to the more cognitively demanding interpretation of treatment risk statistics and making a treatment decision, which also required more complex proportional reasoning, 26% and 6% interpreted treatment risk successfully in two questions and only a quarter of students who attempted this question made a rational treatment choice in their final assessment (see Paper 4).

Making sense of treatment risk information to select treatment rationally and working out the correct dose to be administered to a patient is integral to the work of a clinician treating a patient and a lack of competence jeopardises patient safety and quality of care. Consequently, it is important to try to understand what makes these skills difficult for students so that obstacles can be removed to improve student ability.

It was expected that students would battle most with skills that demanded more complex proportional reasoning involving more reasoning routines or more complicated relationships, such as one percentage as a ratio of another or involving percentage change. This was the case, with students performing better in the three questions assessing lower level proportional reasoning skills in Cycle III, with 55% success, compared with the tasks of risk interpretation (26% and 6% success) and rational treatment selection (26% success) (see Paper 4). As well as involving higher level proportional reasoning, this reasoning was performed in the context of tasks requiring the higher level cognitive skill of evaluation when compared with the skill of 'application' needed to calculate drug dosage. Accordingly, students found these tasks more difficult and scored worse in these than the 66% they scored in the dosage calculation assessments in Cycle I and II. Even the one additional extra step of converting a percentage or a ratio to a mass per volume concentration format in Cycle I made these question types more difficult for students (where they dosed 'patients' incorrectly 43% and 44% of the time) compared with the mass per volume and rate question types (where 'patients' received the wrong dose 25% and 24% of the time)(see Table II in Paper 1).

However, the reason for the difficulty with concentrations in the ratio or percentage format might have less to do with proportional reasoning ability and more to do with these being used in a way particular to chemistry and pharmacology: i.e. that a percentage solution is an amount in grams divided by 100 mL, e.g. *x%* solution = *x* g/100 mL. This is different to the everyday way percentage is used, where *x* % of a solution of 100 mL would be calculated by dividing *x* by 100 and multiplying by 100 mL to give *x* ml. Although students were told this situational information, it is possible they missed hearing it or misunderstood the information. The language difference between 'a 1% solution' and '1% of a solution' is very subtle and it would be easy for a student, particularly one whose home language is not English, to misinterpret the meaning. This example highlights the difficulty involved in measuring proportional reasoning skills in students performing workplace tasks requiring proportional reasoning. Lack of success in these ratio type questions might be a consequence of a difficulty with proportional reasoning, a lack of understanding of the way percentage is being used in the context of describing the solution or a language difficulty that prevents a student picking up the subtle wording differences between the use of percentage to describe a concentration and its everyday usage. In attempting to understand why percentage and ratio dosage calculation question types were more difficult for students, our quantitative data did not allow us to isolate proportional reasoning skills from the context in which it is being used and the language in which it is embedded. For dosage calculations, all are important and need to be considered to build these quantitative literacy-based workplace skills.

The qualitative aspects provide a different perspective and the analysis of the students' risk comparison descriptions provided some insight into their level of relational thinking. Although the question was worded in such a way that it cannot be said that students who compared the two rates correctly in absolute terms could not also have done so in terms of relative risk, students were asked to describe their difference in detail and it is interesting to see how different students understand this instruction. The word 'difference' in the question may also have influenced students to choose to describe the risk in absolute terms. The everyday meaning of the word 'difference' was intended, but students may have understood it in its mathematical context and so presented the absolute risk reduction, one risk subtracted from the other. Consequently, the 10% of students demonstrating that they have crossed the threshold to proportional reasoning competence may be an underestimate of students' ability. What was revealed though was that 24% of students gave absolute values for risk but described it in a way that would appropriately be used to describe relative risk: "*The drug reduces myocardial infarction by 0.5%"* is an example. Again, it is not clear whether students understand risk proportionately and are inappropriately communicating this risk (a linguistic issue) or whether they lack fully competent proportional reasoning, or both. It is important though that students know how to describe risk information precisely. Numbers were not used to describe risk at all by 18% of students, despite being asked to describe the difference between the two histograms in detail. In addition, the previous part of the question allowing students to describe risk without using numbers, implied that in the next part of

the question, something more was required. The 17% who misunderstood the meaning of the histograms lacked the quantitative literacy to make sense of the graph, despite having guidance provided by the first part of the question. If this part of the question had not been included, it is possible that more students may have misinterpreted the histograms. Poor language skills may have contributed to this, as well as the inclusion of contextual information such as the mathematical meaning of the word 'rate' and the word 'placebo' which some students reported not understanding (unpublished data see Section 6.4 of Chapter 6,).

The observed teaching proved to be very fruitful in revealing detailed information pinpointing student difficulties and the strategies that helped them get back on track and keep going until they could calculate a dose successfully, and that they could use again to succeed with the next calculation. Difficulties with understanding concentration as an intensive quantity was revealed as well as other arithmetical and contextual misconceptions. These difficulties and remedies informed changes in teaching material for future large classes in an effort to address these difficulties early on, and the results suggest these seem to be helping students. The observed teaching provided an unexpected and sobering insight into the discomfort students felt when having to confront their difficulties with proportional reasoning skills and having to persevere until they could do them on their own (see Section 4.2.3 Table 4.8). These students had taken the trouble to attend the session and address this lack of competence and showed traits of resilience and courage facing a weakness and struggling though to better understanding (Section 4.3.3 Table 4.10). It was inspiring to see the understanding build and the anxiety ease (Section 4.3.3 Table 4.11) (unpublished data, see Chapter 4). In a time of massified teaching it is important to find ways to strengthen the connection between student and faculty. The students who attended showed improvement during the tuition and for those who were later assessed all showed improved scores (see Paper 2). A future aim for this curriculum would be to identify struggling students early on and offer some form of such individualised tuition so that they are not left feeling overwhelmed and anxious but can iron out problems and start building competence early on. In one-one-one teaching, linguistic difficulties can be more easily diagnosed and remedies made to ensure a student can interpret the information. The benefit of collaborating with students in this way is mutual, because the insights revealed can be fed back to strengthen teaching for the large group to which the students belong, as well as for the cohorts of students that will follow the trailblazers.

Use of inappropriate units was felt to suggest proportional reasoning difficulties because including units in the dosage calculation procedure can be a useful strategy for preventing procedural errors, and correct proportional reasoning should generate correct units. In the example of calculating the amount of medicine required for a 10 kg child requiring a 5mg/kg dose (a 'missing value' problem where the student has been given three values *a, b* and *c* and the student would calculate the fourth *d*) reasoning proportionately should help a student arrive at not only the correct quantity of 50 but also the appropriate

unit mg. It is also possible that inadequate retrieval of numeric information embedded in text might cause the incorrect dosage information to be retrieved- so that an inappropriate quantity- an incorrect number and its attached unit- is used in the calculation, which would also account for the range of inappropriate units used (see Paper 3). For example, students may have mistakenly retrieved the numerical information from 'Pharmacokinetics', an earlier section of the digoxin monograph excerpt. This includes a quantity which is a concentration in mmol/L (the 'therapeutic serum levels', a level of drug in the body associated with a therapeutic effect). This might account for the more obscure units, such as mol. Students only encounter the concept of concentration formally as school in the subject Physical Science, where molar concentration of substances is measured in mol/dm^3, which might partially explain units involving dm^3. Twelve students provided no units perhaps as an oversight. The remaining students- the 40% from groups calculating the dose with no equipment and the 20% calculating and drawing up the dose, are either displaying a lack of proportional reasoning skills, or poor linguistic skills are hampering appropriate information retrieval and preventing students from showing these skills. Again, this shows how difficult it is to isolate proportional reasoning difficulties that might be underlying lack of competence at dosage tasks.

In addition to proportional reasoning difficulties, other mathematical factors influenced students' success in the different tasks. Frith and Lloyd (2016) noted that the type of number affected the ease with which relationships between numbers were recognised, and this was believed to affect the success of students calculating the drug dose in Cycle II. That calculation involved decimals in the formulation concentration and the mg per kg dose. Even after multiplying the mg per kg dose by the patient's weight, three decimal places remained. Difficulties with decimals was one of the top three error categories in the analysis of dosage calculation assessment responses in Cycle I (Section 4.2 Table 4.4). Another problem revealed in Cycle II was difficulties measuring the required volume in a syringe. A fifth of students were unable to measure and prepare the dose they had calculated. Revision of decimals is already included in the QL programme, but the inclusion of examples of real-life decimal errors might cause students to pay attention and flag decimal errors for their special care and attention as their learning is encoded.

The more linguistic skills the task demanded, the more difficult it was for students. For those not receiving instruction or guidelines in their home language, the linguistic demands were greater and it is not surprising that, in every cycle, having English as a home language predicted success, although, encouragingly, in Cycle I, this association was lost by the final assessment. In Cycle II, it was possible to compare students who had to undertake the linguistically more demanding task of navigating guidelines, to retrieve the appropriate numeric information required for calculating a dose, with those calculating a typical drug dose where the numerical information was provided in a short vignette. Students fared significantly better in the groups receiving numerical information than those dealing with

embedded information, achieving 43% and 46% (for calculating only and both calculating and drawing up a dose, respectively) compared with 10% and 25% for the equivalent groups retrieving information from guidelines (see Paper 3). When written responses were analysed, there was no difference in retrieval of the mg/kg information from guidelines between students using equipment and those who did not, but retrieval of formulation information was easier for the groups given a bottle. Only 32%, 42% and 58% of students successfully made it through retrieving the information they needed to even try reasoning proportionally (unpublished data see Table 5.2 in Section 5.2. This is an area that might be strengthened in further classroom teaching focusing on navigation of the guidelines).

When stratified according to home language, English speaking students performed twice as poorly in the embedded questions (42% incorrect) as in the typical ones (19% incorrect) in Cycle II, indicating that retrieval from guidelines is linguistically difficult, requiring comprehension and quantitative literacy skill over and above the additional demands of having to decode language into a different home language (Paper 3 and Section 7.4). Students not having English as a home language also performed more poorly with typical questions but for these the difference in success was less marked, the relative risk for answering a question incorrectly being 1.3 for embedded questions (94% incorrect) compared with typical ones (72% incorrect), perhaps because even retrieving numerical information from the vignette, decoding and making sense of it was linguistically challenging for them. The fact that all students find the workplace skill of retrieving dosage information from guidelines challenging is a strong reason for including opportunities for students to work with these guidelines during training and for the inclusion of questions requiring retrieval of such information in formal assessments.

In addition to difficulties with retrieval of numeric information from guidelines, linguistic difficulties were also evident in the preliminal, liminal and threshold space framework for proportional reasoning when students described the difference between two rates represented graphically. Twelve percent of students deemed to be in the liminal space were held back from crossing the threshold to demonstrating competent proportional reasoning because of inadequate articulation of their reasoning. A further 30% were unable to describe the difference between the two rates articulately and unambiguously in absolute terms, despite providing correct numerical information (unpublished data, see Section 6.4;7.4). Assessment requiring written responses of any kind are rare at our medical school. Although in Cycles I and II students were required to work out dosage calculations and their efforts were analysed, in Cycle III, the formal assessments were of the sort that could be answered on an answer sheet that could be graded electronically. Students need practice in comparing risks and describing them in writing. They need feedback and guidance to see why a particular description of risk is ambiguous, to help them pick up the subtle language differences that change meaning between understanding of risk in absolute or relative terms as a percentage change or a direct comparison of two rates.

Opportunities to read not only excerpts from guidelines but material such as graphs, text and charts from journal articles should be built into the programme so that students see examples of descriptions of treatment risk and how risks are compared. Opportunities to use risk information to critically analyse and examine the evidence behind company literature such as promotional material and advertisements, and the way treatment risk statistics are used to make claims should help build quantitative literacy as well as critical thinking skills. Rule and Land (2017, p. 8) have highlighted a flaw in the way reading is taught in many South African schools, with an emphasis on fluency and correct pronunciation without making sure students have made sense of what they have read or encouraging students to question what they don't understand. The authors consider this 'reading without comprehension' to be 'a consequence of the deliberate emphasis of apartheid era education on unquestioning acceptance of presented form'. Students need opportunities in medical school to continue reading and writing, working with material that encourages them to question, allowing room to remediate any lack of critical thinking skills their schooling has caused, while at the same time strengthening quantitative literacy.

The framework of Lipkus and Peters (2009) includes an intuitive way of understanding numbers that causes people to pay attention to them in the decision-making process This intuitive, maybe 'commonsense' thinking about numbers is an area that needs to be tapped into further in our teaching and strengthened. A remedy for students' uncritical acceptance and a way to strengthen the links between the deliberative components of decision-making around numbers might be to create opportunities for students to ask questions about numbers. A strategy to develop understanding which Madison (2014) describes is the use of student-sourced everyday quantitative material from which they generate learning questions to encourage the use of questioning, such as asking what the numbers mean, what the assertions made are and whether the conclusions are valid. Although this is more difficult in a large group setting, students could be shown an advertisement and the choice of treatment risk format probed. Frankenstein (1983, p. 3), in her explanation of the philosophy of Paolo Freire as it pertains to her critical mathematics education curriculum, says "Knowledge does not exist apart from how and why it is used, in whose interest". Students could then progress to finding an advertisement containing numerical information from journal articles in the library or be provided with samples of promotional material showing a graphical comparison of rates and then asked to work out study questions and present these to the class. This might work well in an online discussion setting or social media forum. This would allow an opportunity for same-language peer discussion, a strategy which, during group tuition in Cycle I, helped close the gap in dosage calculation success between English speaking and non-English speaking students. This intervention, together with offering individual tuition for the weakest students and assessing skills at intervals over an extended period of time, was enough to cause the initial association in Cycle I between having a home language other than English and lack of success, to be lost for that cohort by the end of Cycle I (see Paper 2).

In addition to interventions encouraging same language discussion of treatment risk, students not having English as a home language require additional support. Although the needs of students having a range of home language must be considered, because isiZulu and English are the most common home languages, the effect of offering bilingual instruction in these languages should be explored. In addition, making recordings of the sessions available to students would permit them to access the "foreign" language at their own pace, allowing them to pause and repeat the linguistic material when necessary. This practice, which is already offered to students, should be strengthened. In addition, consideration should be given to providing recordings of interpretations of the lesson material translated into the students' home language. The intervention of a 'Translation club' could be developed and tested, where students connect and play a game in teams where one team is split in two and must translate a piece of written or spoken work into isiZulu and then pass it to the second half of their team who must back-translate it into English. Teams would compete to see who could be fastest and their isiZulu translations could be rated, perhaps with a different year of students to see whose was judged to be best. Written material such as dosage calculations, excerpts from the Standard Treatment Guidelines, adverts and journal abstracts or oral material such as slides from recorded Powerpoint presentations could be used. This could be used to generate more serious endeavours, such as recorded translations of English lectures that could be made available to students, and even the beginnings of the South African Standard Treatment Guidelines translated into isiZulu and other African languages.

Artefacts such as formulations and measuring equipment were expected to guide students and prevent them from calculating implausible doses. In Cycle II, there was no statistically significant difference between students who received this equipment and those who did not. Because students' ability to measure doses with a syringe had been assumed, this skill had not been taught. However, their ability had been underestimated and 22% of students who had been asked to calculate and draw up a dose made measurement errors (see Paper 3). As a consequence, teaching has changed to include syringe measurement skills, and images of artefacts such as administration sets, vials and ampoules and infusion solutions in 'minibags'. A follow-up study after such training might show an association between receiving dosage equipment and student dosage calculation success. Despite the measurement errors, the provision of a bottle of 'formulation' and a syringe made students who had to retrieve numerical information from guidelines two and a half times as likely to dose correctly compared with those who did not receive this dosage equipment (see Paper 3). Students were also found to experience less retrieval problems with formulation information when given these artefacts, because the formulation information was labelled on the bottle. These artefacts, or clearly labelled pictures or diagrams should be included in assessments to allow students to access this information which would be available in the workplace.

The measuring limits provided by the syringe prevented students using equipment from making as many implausible errors. Feasible responses that could actually be measured with the syringe rose from 56% to 84% when students used equipment (see Paper 3) Artefacts may assist the connections between the deliberative and intuitive processing of numbers described by Lipkus & Peters (2009), and this would be interesting to explore.

Bringing contextual information into the classroom and into assessment is expected to have other benefits, including learning the proportional reasoning in a pattern in which it would naturally occur in the workplace. This encodes the procedural proportional reasoning routine selected together with situational information, such as the type of formulation, in a way that is expected to make the information more accessible and transferable in a workplace situation (Stasz, 2001). A factor highlighted by Frith and Lloyd (2016) as affecting the difficulty of a paper problem is students' familiarity with reasoning proportionally in a particular context. If some of the contexts, where proportional reasoning is required to competently prescribe and administer treatment, is introduced to the classroom and discussed, and students can practice reasoning proportionately in this setting, it will remove the unfamiliarity and decrease the difficulty when students encounter the information in the workplace. Students commented that they did not know what the word 'placebo' meant, and some could not interpret the histograms in Cycle III. This unfamiliarity with the context of randomised controlled drug trials in which the treatment risk information is generated might have contributed to students' low level of success with these statistics. In response, in a class activity, students now become participants in a quick mock 'drug' trial in which they are randomly assigned to a placebo or treatment group (take coloured paper from a jar), the meaning of placebo is explained and those who find a cross on their square of coloured paper become patients, with negative events. Students are counted to generate numbers of events within the two populations and a class event rate chart is generated from which the different risk statistic formats are calculated. It is hoped that this activity will help students come to terms with events and event rates, and get to grips with the different treatment risk statistics. Also, in keeping with recent literature, we now look at how to describe treatment risks as pictograms, which have been found to be better interpreted by patients than other representations of treatment risk (Sprague et al., 2011). This format might help students better interpret risk as well as enable them to explain risk to future patients in a way that is most likely to be understood.

Proportional reasoning demonstrated in the context of a particular quantitative literacy task is embedded in the language and situational factors of that task. Students' ability to succeed at proportional reasoning-based skills is closely connected to the context in which they are reasoning and to the task displaying the skills. In the same way, language is an inextricable part of demonstrating proportional reasoning. Although it is not possible to separate language and situational causes from mathematical difficulties, this research hints at definite areas where some students have mathematical deficits. One

example is that, in Cycle II, 20% of students with equipment and 40% without used a range of 12 inappropriate units including no units at all. Although linguistic deficits could prevent adequate retrieval of the right piece of numerical information to perform the calculation, an understanding of intensive quantity should make students realise that, for example, in order to work out a volume, when given an amount (in units of mass), that a quantity must be retrieved that relates amount (or mass) to volume. Expressing a volume using some sort of unit of volume would be expected of students who have achieved excellent school mathematics results. Another is the fact that 20% of students were not able to work out from the labels and syringe divisions how to draw up the dose they had calculated. For a cohort of students achieving a mean school mathematics score of 80%, this is surprising, even if this was a newly encountered piece of measuring equipment (see Paper 3).

The main approach to teaching school mathematics has been 'traditional, formal and authoritarian' (Venter et al., 2004, as cited in Barnes, 2005, p. 50). These authors describe the way in which mathematics lessons are presented: first the introduction of relevant new mathematics language, used in a particular topic, then students are shown how to use the appropriate algorithm with a few worked examples and then given some examples and contextualised problems to try on their own. South African government schools have moved to a system of a standardised curriculum, materials and lesson plans, which reinforces this teaching style. Like the focus on reading performance at the expense of understanding (Rule & Land, 2017), this type of mathematics may cause an over-reliance on algorithms and procedural information at the expense of understanding why this procedure is being followed. These algorithmic methods, according to Frith and Lloyd (2016), cause students to lose touch with their natural ability to reason proportionately. This links back to the place of intuitive processing of numerical information described by Lipkus and Peters (2009). It would appear from this study that school mathematical success does not necessarily mean a student can think critically about numbers. School teaching and assessment may not be rewarding Bloom's higher-level skill of evaluation, i.e. the ability to judge (Krathwohl, 2002). Consequently, students seem to be less prepared and able to evaluate whether a dose can fit in a syringe, whether a unit makes sense, whether a particular drug is the most effective based on objective criteria, and whether number sizes in different risk statistics can all be different but describe the same risk and be designed to mislead. A primary role of university is to develop critical thinking skills, and the challenge is to develop the curriculum to find ways that support students to build this capacity as their contextual understanding, and proportional reasoning and linguistic skills develop.

Table 9.1 Implications and recommendations

Problem	**What still needs to done**	**Implications** policy, theory, educational practice and research
Typical dosage calcs	Reach third of students not competent after 1 year	**Policy and practice**: Evidence for benefit of and continued need to provide early and extended dosage calculation tuition opportunities for peer-learning and discussion in students' preferred language individual tuition for struggling students provision of visual contextual information provision of conceptual explanation of concentration as an intensive quantity revision of procedural skills eg unit conversion **Research**: Need to find ways for earliest identification of students struggling with proportional reasoning or linguistic skills so they can access individual tuition while avoiding any associated stigma Need to track students for improvement, throughout the preclinical yers
Extracting dosage information from guidelines	Reach 90% not yet successful (75% with dosage equipment) Reach % not retrieving from guidelines (68%), 57% bottle + guidelines, 42% bottle	**Policy:** Retrieval of doage information should be taught and assessed explicitly **Educational practice:** Strengthen tuition with additional lecture material (pointing out pitfalls to avoid dirng navigation of guideline) additional tutorial material (eg information retrieval worksheet, monograph reading comprehension) Explicitly teach that the formulation concentration can be found on the label if given the bottle of formultion **Research** Track students for longer to determine how much skills build at medical school
Preparing a dose in a syringe	Reach fifth who couldn't not measure dose	**Policy and practice** related to curriculum: Has led to curriculum change to include syringe measurement tuition **Research** Need to evaluate the benefit of tuition and of the inclusion of dosage equipment or visual information in assessmen
Incorrect units	Reach 40% incorrect without & 20% with equipment	**Practice**: Strengthen tuition by try ingthe following: what pitfalls to avoid while extracting quantities during guideline navigation tuition explicit instruction to continue calculation past the milligram dose to find the volume of formulation needed modelling of use of units during every stage of the calculation process and discussion about whether a unit makes sense Share anonymised incorrect units calculated by previous cohorts and ask students why they must be incorrect
Decimal errors	Find out the size of the problem	**Practice**: Strengthen tuition by trying the following: Revision of decimal skills as part of initial tuition Highlighting of the dangers of this error to strengthen mindfulness about numbers (eg the importance of checking and engaging pragmatic thinking to avoid careless mistakes) Need to include early assessment of decimal skills to identify students still struggling who could benefit from individual tuition

Table 9.1 (continued) Recommendations and Implications

Problem	**What still needs to done**	**Recommendations and Implications** for policy, educational practice and research
Graph comprison	Reach 90% not crossed the threshold, quarter not at preliminary stage	**Practice** Student mapping of anonymised data as a class activity to show need for careful language use with percentage, test effect Fill in the blank assessments→ % comparison writing practice **Research** Determine effect of tuition with a follow up test Test effect of classroom simulated randomised controlled trial
Treatment chart interpretation and rational treatment choice	Reach three quarters not interpreting relative risk or rational decision and 94% struggling with absolute risk and NNT	**Practice** Introduce opportunities to generate learning questions from student-sourced everyday or medical quantitative material e.g. adverts and to discuss with peers, test effect Include graphs, results charts, advert risk statistics in therapeutics teaching in themes throughout preclinical years **Research** Separate ARR and NNT and measure each Effect of extended time, repeated assessment, peer tuition Test effect of Classroom RCT: use numbers to generate results chart, risk statistics, pictograms, graph, statements, test effect
Support for students not having English as a home language	Reach the 72% & 94% incorrect typical dosage calculations & from guidelines. Reach 85%, 96% incorrect treatment chart interpretion of relative, absolute risk Reach 80% not making rational selection	**Policy** Need to offer additional support to students who have to decode the learning into a home language other than English **Practice**: Has led to curriculum change to include Recorded lectures and teaching material to follow at own pace **Practice and research** Peer tuition has led to improvements in dosage calculation, need to build and test this for retrieval of numerical dosage information and interretation of risk statistics-consider social media options Test effect of bilingual instruction, translated recordings Test effect of a translation club: small group translation & back-translation of -written material: e.g. dosage calculations, STG excerpts, adverts and journal abstract;-spoken material e.g. recorded Powerpoint lecture slide Introduce opportunities to generate learning questions from student-sourced everyday or medical quantitative material e.g. adverts and to discuss with peers, test effect while including source material of home languages other than English (e.g. isiZulu newspaper)
Need to strengthen commonsense and Critical thinking about numbers		**Policy** **Dosage** Equipment helped prevent implausible doses and should be included in tuition and assessment **Practice and research:** Introduce 0pportunities to generate learning questions as described previously **Practice** Share anonymised implausible dosage volumes calculated by previous cohorts and ask students why they must be incorrect

9.4 Overall significance of the study

In summary, this study shows that students should receive early dosage calculation tuition, which should be repeated over an extended period to allow for the development and retention of skills. Tuition should include visual contextual material and explanations about the concept of concentration and the unusual use of percentage in the conventions of percentage concentration. Basic arithmetic skills such as unit conversion and decimals need revision and students need to be made aware of the dangers in practice of decimal errors to combat carelessness. This study shows that tuition that included these elements was associated with development of dosage calculation competence over a shorter period. Retrieval of numerical dosage information from guidelines and interpretation of treatment risk information are important skills for practice and were both shown to need to be needed in tuition and assessment. Both of these skills depend on linguistic skills, and the numbers generated need to be evaluated critically and pragmatically to check that they are plausible. When retrieving dosage information, dosage equipment provides a practical limit which assists with commonsense evaluation independent of language and this study shows it improves student success at calculating doses. This benefit depends on students having the ability to measure a dose with a syringe, a skill which this study showed should not be assumed but instead taught explicitly.

Current tuition needs strengthening, particularly for retrieval of numerical information and interpretation of risk statistics. There is room to improve more conventional tuition and assessment to track students 'progress. In addition, promising strategies, which target the underpinning linguistic and pragmatic gist-making skills also involve peer learning, which has been found to mitigate some of the disadvantage of receiving tuition in a home language other than the language of instruction. One strategy includes opportunities for students to generate learning questions about numbers sourced from everyday multilingual sources and from medical information such as advertisements, in order to generate curiosity and discussions about the numbers. A second, involving students collaborating to interpret and translate teaching material into different languages, would require careful scrutiny of these materials and therefore should cause students to comprehend them better.

9.5 Conclusion

Successful drug dosing practices depend on being able to make sense of underlying mathematical, linguistic and contextual information. Qualitative research in the form of observed individual tuition and analysis of students' written responses can help pinpoint weaknesses and misconceptions which can be remedied for the group as a whole through teaching changes. Quantitative research can test the benefits of new remedies.

Introducing workplace artefacts such as treatment guidelines, formulations and syringes helps prepare students, allowing them to practice in a way that facilitates transfer to the workplace. Training and teaching changes can help students, but if they are to become competent, all students, but especially non-English speakers, need different kinds of tuition and assessment at intervals over an extended period. Students need opportunities to write about treatment risks, to read scientific literature, critically evaluate drug company material and to learn to ask questions about numbers and those who generated them.

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11 August

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

COLLEGE OF HUMANITIES

MASTERS/PHD RESEARCH PROPOSAL AND ETHICAL CLEARANCE APPLICATION
(HUMAN AND SOCIAL SCIENCES)

PLEASE NOTE THAT THE FORM MUST BE COMPLETED IN TYPED SCRIPT. HANDWRITTEN APPLICATIONS WILL NOT BE CONSIDERED

SECTION 1: PERSONAL DETAILS

1.1	**Full Name & Surname of Applicant :**		Catherine Sara Harries
1.2	Title (Ms/ Mr/ Mrs/ Dr/ Professor etc)	:	Mrs
1.3	Applicants gender	:	female
1.4	Applicants Race (African/ Coloured/Indian/White/Other)	:	White
1.5	**Student Number** (where applicable)	:	871871463
	Staff Number (where applicable)	:	800528
1.6	School	:	School of Education
1.7	College	:	College of Humanities
1.8	Campus	:	Edgewood
1.9	Existing Qualifications	:	BSc(pharm); PGDip(higher ed); MMedSci(pharmacol); MEd(higher ed)
1.10	Proposed Qualification for Project (In the case of research of degree purposes)	:	PhD

2. Contact Details

Tel. No. : (031)3031833 (h); (031)2604337 (w)

Cell. No. : 0832312761
e-mail harriesk@ukzn.ac.za
Postal address (in the case of studets
and external applicants) : 39 Rapson Road, Morningside, Durban, 40

Proposal for:

PhD Thesis:	**100%**	**100 000 words**	**384 credits**
Dissertation	**100%**	**40 000 words**	**192 credits**
Coursework Dissertation	**66.6%**	**28 000 words**	**128 credits**
Short Dissertation	**50%)**	**20 000 words**	**96 credits**
Treatise	**33.3%**	**14 000 words**	**64 credits**

In the case of coursework degree, provide a brief description of degree programme:
(e.g., nature of degree, number and na mes of modules passed)

Each research proposal should be submitted together with a fully completed

- ***Contract between Supervisor and Candidate.***

We are satisfied with the academic merit and viability of the proposal and research project, subject to ethical clearance:

1 ***Supervisor:***

Name:.....Signature:.....Date:..... .....
.....

2. ***Academic Leader (Discipline):***

Na me:.....Signature:.....Date:..... .....
.....

3. ***Academic Leader (Research)***

Name:... ..... Signature:.....Date:.....
.....

3. SUPERVISOR/ PROJECT LEADER DETAILS

NAME	TELEPHONE NO.	EMAIL	DEPARTMENT / INSTITUTION	QUALIFICATIONS
3.1 Prof Julia Botha	(031)2604337	BOTHA@ukzn.ac.za	School of Health Sciences, College of Health Sciences	PhD
3.2 Prof Renuka Vithal	(031)2602988	vithalr@ukzn.ac.za	Teaching and Learning	PhD

3.2 Prof Renuka Vithal	(031)2602988	vithalr@ukzn.ac.za	Teaching and Learning	PhD

SECTION 2: PROJECT DESCRIPTION

2. 1. Project title (40 words)
(Give a short title, be specific, include key terms)

Investigation into drug dosage practices and proportional reasoning in mathematics among medical students.

2.2. Brief motivation/Background (200 words)

The numera te individual uses quantitative skills to understand the mathematical challenges of the workplace (Orrill as cited in Steen, 2001). A definitive case statement has been developed, listing behaviours, and their underpinning skills, involving this kind of th inking, which is also called quantitative or mathematical literacy (Steen, 2001). Those relevant to clinicians treating patients include rational drug selection, helping patients understand different treatment option risks, and administering drugs in an ap propriate amount and rate. Rational prescribing depends on an understanding of different ways of representing risk: ratio concepts which include risk ratios, absolute and relative risk, and the 'number of patients needed to treat', abbreviated as NNT (Ther apeutics Letter Working Group, 1996). Communicating treatment option risks to patients involves an understanding of how these different risk representations may influence the patient's choice of treatment and an ability to represent risk in different ways to assist a patient in making sense of the numbers. Dosage calculations of drugs in solution require an understanding of an intensive quantity, concentration, which relates the mass of a drug in solution to the volume of the solution. The drug concentratio n may be represented in either a mass/volume format, as a ratio or as a percentage. Choosing an appropriate rate at which drugs to be administered by infusion are given is dependent on another intensive quantity: flow rate.

2.3. Review of Literature (400 words)
(Outline previous work/literature relevant to your study, who are the main thinkers/researchers/protagonists in the area? Please do not provide long annotations but

demonstrate a broad awareness of the body of literature that exists on your topic. Show where there are gaps and limitations in current research and how this study will seek to make a contribution to the academic debate)

The numerical skills underlying drug therapy involve proportional reasoning, listed in Steen's case statement as a key arithmetic skill (Steen, 2001). Proportional reasoning is in fact widely considered to be a threshold concept, described by Lloyd and Fri th (2013) as a gateway that must be passed through in order to reach fuller ways of understanding (in this case of quantitative literacy). Before students successfully cross this threshold, they may experience a transition state, which will be prolonged fo r more difficult concepts, where student understanding swings from a more superficial to a deeper conception. This conceptual space is referred to as the liminal space. Prior to this, a student is said to be in a preliminal stage of understanding.

Because medical students have achieved in school mathematics, a requirement (UKZN website) for a fiercely contested place in medical school, and mathematics taught in school has been thought to transfer to the mathematics encountered outside school (Stasz, 2001), students have been expected to have proportional reasoning skills that can readily be transferred to the clinical setting. However, school mathematics success does not necessarily guarantee numeracy in the workplace. Research suggests that mathematical k nowledge transfer does not happen readily (Stasz, 2001). Steen (2001) explains that mathematics becomes increasingly abstract. The disconnect between skills demonstrated in paper and pencil tests and those shown the workplace goes further, as revealed in r ecent ethnological studies of mathematics in the workplace, where for example, nurses who may be unable to perform drug dosage calculations on paper may demonstrate drug dosing competence in the ward., employing different reasoning strategies to do so (Hoy les, Noss & Pozzi, 2001; Stasz, 2001).

This evidence of the intricate connection between context and both the acquisition and demonstration of a skill have implications for the acquisition and assessment of proportional reasoning. It would be expected that students would acquire proportional reasoning skills transferable to the workplace when these are learned during exposure to as many contextual factors as can be achieved within the limits of ethical considerations and the constraints of the

classroom. Students would also demonstrate different levels of ability which would be more or less relevant to workplace numeracy depending on the extent to which authentic contextual factors relevant to the workplace are included in the assessment.

Vithal (2012) argues that the mathematically literate individual should be empowered to go beyond functional literacy to ask why the numbers have been formatted in a particular way, how the chosen format serves the producers of the figures, and how the numbers would be interpreted in they were formatted in a different way. Clinicians must use this kind of thinking to assess numerical risk information presented in guidelines, journals and company literature such as advertisements in order to guide a patient in making an appropriate treatment choice. Among law and humanities students, difficulties with proportional ratio concepts impeded the development of their ability to reason critically about quantitative information. (Lloyd and Frith, 2013) It is not known what impact the proportional reasoning skills of medical students have in the context of such a task involving critical reasoning.

Consequently the present study will add to the literature by looking at the ability of medical students to show proportional reasoning skills in different contexts and for different tasks.

2.4. Location of the Study (For Empirical Studies Only) (100 words)

(Geographic – spatial, Temporal – time period, Social – socio-political-economic context)

Dosage error remains an important source of morbidity and mortality worldwide (Lewis et al., 2009; Simpson, Gerben, and Lind, 2009) and irrational prescribing is associated with suboptimal treatment and unnecessary health risks and costs (De Vries, Henning, Hogerzeil & Fresle, 1994; Hogerzeil *et al.*2001). Among doctors, clinicians in Australia are less competent at dosing than they believe they should be (Simpson, Gerben, and Lind, 2009). Difficulty with ratio concepts accounts for most suboptimal mathematical proficiency and predicts poorer health outcomes in the USA (Reyna and Brainerd, 2007).

Such difficulties also cause medical students to struggle with drug dosage calculations when the concentration is expressed as a ratio or percentage (Wheeler, Remoundos, Whittlestone, House, & Menon, 2004). Drug dosing has also been alluded to as a problem among South African medical students (Harries, Mbali, & Botha, 2006), but the extent and nature of the

problem is not known. For law and humanities students at university, proportional reasoning is a threshold concept for numeracy and critical thinking that very few students have reached (Lloyd and Frith, 2013). Our papers will be the first to investigate proportional reasoning among South African medical students.

2.5. Objectives

(Set out the major objectives/aims of the study State these explicitly e.g:)
"The objectives of this study are:

1. To ....
2. To...
3. To...

This research will explore the nature of proportional reasoning skills demonstrated, and the effect of contextual factors, when medical students are engaged in different tasks typical of those that will be encountered during the provision of drug therapy for patients.

The thesis will be by publication and the measurable outcomes will be these publications. In these the aim is to achieve the following:

Objective 1. To investigate the nature of the proportional reasoning knowledge and skills medical students demonstrate when calculating drug doses from paper problems after exposure to different learning contexts.

Publication 1: Harries, C., & Botha, J. (2013) Can medical students calculate drug doses? *South African Journal of Anaesthesia and Analgesia, 19*(5):248-251

Publication 2: Harries, C., & Botha, J. (2013) Assessing medical students' competence in calculating drug doses. *Pythagoras, 34*(2), Art.#186, 9 pages. http://dx.doi.org/10.4102/pythagoras.v3412.186

Objective 2. To investigate the nature of students' ability to do proportional reasoning in the workplace-related contexts of:

i) needing to extract embedded information from guidelines in relation to calculating drug doses.

ii) needing to actually manipulate the syringes and formulations to prepare the drug dosage for parenteral administration

Publication 3: To be submitted to the journal Educational Studies in Mathematics.

Objective 3. Investigate the nature of students' ability to show their proportional reasoning knowledge and skills in the context of assessing data that gives drug therapy risk/benefit information.

Publication 4: submit paper to Medical Education Journal

2.6. Questions to be Asked

(Set out the critical questions which you intend to answer by undertaking this research –these must be directly correlated to the objectives)

Research Question 1.

What is the nature of the proportional reasoning skills medical students demonstrate when calculating drug doses from paper problems after exposure to different learning contexts? When students are supplied with the appropriate numerical values, how do they fare in paper and pencil assessments? Do they improve with time and practice, group or one-on-one tuition? What is the nature of the proportional reasoning demands underlying the different kinds of calculation and which are most problematic?

Research Question 2.

What role do drug dosage contextual factors in assessment play in students' ability to demonstrate proportional reasoning skills? How do skills compare when contextual factors relevant to the demands of the workplace are increasingly included in the assessment? How do students fare in written assessments when extracts from guidelines are provided and their embedded numerical values must be extracted in order to calculate drug doses. How does this compare with a situation where they must not only consult guidelines and package inserts, to find the relevant dosage information, but must also actually manipulate the syringes and formulations in performance assessments to prepare the drug for parenteral administration?

Research question 3.

What is the nature of students' ability to show their proportional reasoning knowledge and skills when performing a drug therapy task demanding critical thinking? How does this compare with the proportional reasoning skills they show with the less cognitively demanding task of dosing drugs? According to threshold concepts theory, have students crossed the threshold to a

deeper way of understanding risk statistics and the percentage change they describe? If not, at what stage are they in developing these skills?

2.7. Research Methods / Approach to Study (400 words)

(Explain *how* you will go about answering the main research questions and the approach within which you will work. Describe the design of the study, sampling and sampling method with rationale, data collection methods, data analysis methods - be specific)
In **Appendix One** you are required to attach copies of all your **'instruments'**: questionnaires; discussion outlines, interview schedules/questions; coding sheets etc.

This longitudinal study employs a mixed method study design. As a starting point for exploring student ability to demonstrate proportional reasoning knowledge and skills when dosing drugs or using risk statistics to facilitate rational drug selection in different contexts, a normative approach has been and will be used. The responses of all medical students in a particular year of study are entered in an Excel® 2007 spreadsheet and the calculation of descriptive and inferential statistics (including mean and range, and Chi-squared testing) using Epi-Info (Version3.4.3) is included in the analysis.

A key characteristic of this normative approach is that it is underpinned by a philosophy which is dualist in nature, meaning that the individual or subject is believed to be a separate entity from the skills demonstrated. However, this approach to the study of human behaviour has been criticised because it fails to consider the unique ability of the human to interpret and represent experiences and it ignores or presumes its subjects' interpretation of situations. Interpretive research approaches probe the accounts of a study subject's actions in order to understand what the subject was doing during a particular social episode of interest (Cohen, & Manion, 1980). Cohen and Manion explain that the perspectives of both normative and interpretive approaches are necessary and inseparable aspects of understanding human behaviour and experience and this view is echoed by other authors. (Cohen & Manion, 1980; Neuman, 2000; Entwistle & Ramsden1983). They recommend using mixed quantitative and interpretive methods in order to look at a phenomenon from different perspectives and benefit from the strengths of the different methods.

Consequently, we also take an interpretive approach. Responses from the quantitative component are stratified according to ability demonstrated or the nature of the response and then as a starting point, students are randomly sampled from each of the groups of interest and invited for an interview and an opportunity to work one-on-one with a teacher through questions

previously answered incorrectly. Such student interviews provide the opportunity to get an insight into the student's experience. Content analysis is employed to examine and gather data from written open-ended student responses, interview transcripts and interviewer notes. These are analyzed according to key themes, such as common key problems, and strategies to remediate such problems, using QSR NVivo 8, a software package for qualitative data analysis (QSR International, 2008).

In order to plot student progress towards mastery of proportional reasoning, within the framework of threshold concept theory, as this progress is demonstrated when different work-related opportunites are provided, the framework developed by Lloyd and Frith (2013), which includes a phenomenographic method, will be used.

2.8. Validity, Reliability and Rigour: 400 words (in the case of empirical research)

(Provide a brief account of the validity and rigour of your study predicated on your theoretical/methodological approach. What are the limitations of your study?)
In **Appendix Two** illustrate how informed consent is to be achieved by providing a copy of an **informed consent** form (including translations if appropriate).

Quantitative components

Validity

The use of student responses to written tests has been used because this data will provide a broad view of student ability in the workplace. However, this type of data has shortcomings related to internal validity. It is recognized, for example, that student ability to correctly answer a written dosage calculation is not an exact measure of the intended phenomenon: being able to demonstrate proportional reasoning knowledge and skills when administering the correct dose of a drug to a patient. For example, a student who can correctly answer written dosage calculations for a hypothetical situation may make errors when presented with the reality of calculating in a setting where there are multiple things to attend to at once. Nurses may use contextual information so that they may be able to correctly calculate drug doses at the workplace while not being able to correctly answer a similar written dosage calculation involving an unknown drug ((Pozzi, Noss, & Hoyles, 1998). A focus of this study is a comparison of student demonstration of proportional reasoning knowledge and skills in different contexts.

Reliability

The material and people studied will relate to the experiences of particular groups of students all at a particular stage in their studies. Students in a particular stage of their studies and material relating to this may change substantially between groups at the same stage but studying at a different time, which would interfere with the reliability of the study. Where possible, the results of students at the same stage of study but starting in different years will be combined to reduce this problem.

Qualitative component

Trustworthiness

According to Shenton (2004), Guba proposes four criteria, namely credibility, transferability, dependability and confirmability, that should be considered in developing a trustworthy study using a qualitative approach.

This study will include several of Shenton's recommendations, namely random sampling, detailed description of the phenomenon under scrutiny and triangulation of methods to ensure confidence in the credibility of a study.

Sampling: Purposive sampling, where outliers are deliberately sought out to reflect the diversity within a given population is a valuable tool used in qualitative research to bring subtle but potentially important differences to the researcher's attention. In this study, for example, in order to understand why students are having difficulties, the weakest students are invited for interview in order to collect the most detailed information about student difficulties and strengths. A stratified random sample of students making errors will also be interviewed, to ensure that the experiences of outlying students could be compared with those more representative of the mean.

Provision of a thick description of the actual situations within which student ability is or is not demonstrated, will, as well as ensuring confidence in the credibility of the study, also allow other researchers to determine the transferability of the results to similar settings.

Triangulation involving the use of both quantitative and qualitative methods to measure student ability will compensate for the limitations of each method.

The use of different methods will foster confidence in the dependability and confirmability of the study, as will a detailed description of the methods employed.

2.9. Proposed work plan

(Set out your intended plan/timetable of work for the research, indicating important target dates necessary to meet your proposed deadline as agreed with your supervisor).

GANTT CHART for proposed work schedule for PhD project

Key Tasks	2012		2013		2014		2015	
	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec	Jan-Jun	Jul-Dec
Register for PhD								
Data collection, analysis & submission of paper 1 & 2								
Data collection and analysis for paper 3								
Revisions and proofreading paper 1								
Revisions and proofreading paper 2								
Data collection and analysis for paper 4								
Proposal revision								
Write up for paper 4								
OSPE Data collection& analysis for paper 3								
Write up for paper 3								
Write up of abstract integrating papers								
Collation and printing of thesis								
Submission of thesis								

2.10. Cost Estimate

(Provide a working budget for your research)

Not applicable

2.11. Anticipated Problems/Limitations

(What problems may occur with your project, and how would you deal with them? Logistical/ethical/theoretical)

I anticipate some sampling problems where randomly sampled students invited for interview and individualised tuition do not show up. I plan to select the next person on the stratified list and to persevere with this strategy until a replacement student is found for interview.

2.12. References

(Provide a list of references. Keep to the 'house style' of your School: Psychology – APA; History –
Footnotes, Others – Harvard).

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SECTION 3: ETHICAL ISSUES

The UKZN Research Ethics Policy applies to all members of staff, graduate and undergraduate students who are involved in research on or off the campuses of University of KwaZulu-Natal. In addition, any person not affiliated with UKZN who wishes to conduct research with UKZN students and / or staff is bound by the same ethics framework. Each member of the University community is responsible for implementing this Policy in relation to scholarly work with which she or he is associated and to avoid any activity which might be considered to be in violation of this Policy.

All students and members of staff must familiarize themselves with AND sign an undertaking to comply with the University's "Code of Conduct for Research".

QUESTION 3.1

Does your study cover research involving:	YES	NO
Children		
Persons who are intellectually or mentally impaired		
Persons who have experienced traumatic or stressful life circumstances		
Persons who are HIV positive		
Persons highly dependent on medical care		
Persons in dependent or unequal relationships		
Persons in captivity		
Persons living in particularly vulnerable life circumstances		

If "Yes", indicate what measures you will take to protect the autonomy of respondents and (where indicated) to prevent social stigmatisation and/or secondary victimisation of respondents. If you are unsure about any of these concepts, please consult your supervisor/ project leader.

QUESTION 3.2

Will data collection involve any of the following:	YES	NO
Access to confidential information without prior consent of participants		
Participants being required to commit an act which might diminish self-respect or cause them to experience shame, embarrassment, or regret		
Participants being exposed to questions which may be experienced as stressful or upsetting, or to procedures which may have unpleasant or harmful side effects		
The use of stimuli, tasks or procedures which may be experienced as stressful, noxious, or unpleasant		
Any form of deception		

If "Yes", explain and justify. Explain, too, what steps you will take to minimise the potential stress/harm.

QUESTION 3.3

Will any of the following instruments be used for purposes of data collection:	**YES**	**NO**
Questionnaire		
Survey schedule		
Interview schedule		
Psychometric test		
Other/ equivalent assessment instrument		

If "Yes", attach copy of research instrument. If data collection involves the use of a psychometric test or equivalent assessment instrument, you are required to provide evidence here that the measure is likely to provide a valid, reliable, and unbiased estimate of the construct being measured. If data collection involves interviews and/or focus groups, please provide a list of the topics to be covered/ kinds of questions to be asked.

QUESTION 3.4

Will the autonomy of participants be protected through the use of an informed consent form, which specifies (in language that respondents will understand):	**YES**	**NO**
The nature and purpose/s of the research		
The identity and institutional association of the researcher and supervisor/project leader and their contact details		
The fact that participation is voluntary That responses will be treated in a confidential manner		
Any limits on confidentiality which may apply		
That anonymity will be ensured where appropriate (e.g. coded/ disguised names of participants/ respondents/ institutions)		
The fact that participants are free to withdraw from the research at any time without any negative or undesirable consequences to themselves		

The nature and limits of any benefits participants may receive as a result of their participation in the research		
Is a copy of the informed consent form attached?		

If not, this needs to be explained and justified, also the measures to be adopted to ensure that the respondents fully understand the nature of the research and the consent that they are giving.

QUESTION 3.5

Specify what efforts been made or will be made to obtain informed permission for the research from appropriate authorities and gate-keepers (including caretakers or legal guardians in the case of minor children)?

QUESTION 3.6

STORAGE AND DISPOSAL OF RESEARCH DATA: Please note that the research data should be kept for a period of at least five years in a secure location by arrangement with your supervisor.
How will the research data be disposed of? Please provide specific information, eg shredding of documents incineration of videos, cassettes, etc.

QUESTION 3.7

In the subsequent dissemination of your research findings – in the form of the finished thesis, oral presentations, publication etc. – how will anonymity/ confidentiality be protected?

QUESTION 3.8

Is this research supported by funding that is likely to inform or impact in any way on the design, outcome and dissemination of the research?	YES	NO

If yes, this needs to be explained and justified.

QUESTION 3.9

Has any organisation/company participating in the research or funding the project, imposed any conditions to the research? YES/NO

If yes, please indicate what the conditions are.

SECTION 4: FORMALISATION OF THE ETHICS APPLICATION

APPLICANT

I have familiarised myself with the University's Code of Conduct for Research and undertake to comply with it. The information supplied above is correct to the best of my knowledge.

NB: PLEASE ENSURE THAT THE ATTACHED CHECK SHEET IS COMPLETED

.....

.....

SIGNATURE OF APPLICANT

DATE

SUPERVISOR

NB: PLEASE ENSURE THAT THE APPLICANT HAS COMPLETED THE ATTACHED CHECK SHEET AND THAT THE FORM IS FORWARDED TO YOUR SCHOOL ETHICS COORDINATOR FOR FURTHER ATTENTION

DATE: .....

SIGNATURE OF SUPERVISOR/ PROJECT LEADER

:_____

RECOMMENDATION OF SCHOOL ETHICS COORDINATOR

The application is (please tick):

	Approved *
	Recommended and referred to the Human and Social Sciences Ethics Committee for further consideration
	Not Approved, referred back for revision and resubmission

* Senate has delegated powers to School Committee to:

- Approve Undergraduate and Honours projects
- Approve Masters projects (if the required capacity exists within the School)
- Approve PhD projects (if the required capacity exists within the School)

NAME OF CHAIRPERSON:

_____SIGNATURE:_____

DATE .....

RECOMMENDATION OF SCHOOL RESEARCH ETHICS COMMITTEE
NAME OF CHAIRPERSON:_____SIGNATURE_____ _____ DATE.....

UNIVERSITY OF KWAZULU-NATAL
RESEARCH OFFICE
COLLEGE OF HUMANITIES

CHECK SHEET FOR APPLICATION

PLEASE TICK

1. Form has been fully completed and all questions have been answered	
2. Questionnaire attached (where applicable)	
3. Informed consent document attached (where applicable)	
4. Approval from relevant authorities obtained (and attached) where research involves the utilization of space, data and/or facilities at other institutions/organisations	
5. Signature of Supervisor / project leader	
6. Application forwarded to School Ethics Coordinator for recommendation and transmission to the Research Office	

1.2 Thesis Proposal report

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

HIGHER DEGREES DISSERTATION/THESIS PROPOSAL REPORT FOR RESEARCH MASTERS/PhD STUDENTS

(This report is to be completed by the appointed scribe or Postgraduate Administrator after the proposal panel has met and thereafter submitted to the Supervisor)

DATE OF ORAL PRESENTATION: 11 August 2014

NAMES OF CHAIRPERSON AND PANEL MEMBERS PRESENT:

Chairperson: Prof S Bansilal

Dr T Sommerville

Dr AA James

STUDENT NAME: **Ms Catherine Harries**

STUDENT NUMBER: **871871463**

DEGREE: **PhD**

DISCIPLINE: **Higher Education**

SHORT DESCRIPTIVE TITLE: **Investigation into drug dosage practices and proportional reasoning in mathematics among medical students**

SUPERVISOR/S: **Prof J. Botha; Prof R Vithal**

ETHICAL CLEARANCE CODE:

GREEN: *No human subjects*

ORANGE: *Human subjects but research not of a sensitive nature*

RED: *Human subjects and research of a sensitive nature:*

1. **Please document the findings of the panel in respect of the categories below. Where no comment was made indicate so:**

- **The general impression of the study:** The study is feasible. The members of the panel felt that the focus of the study was important and had the potential to contribute to new knowledge.

- **The literacy style and presentation:** Good. Occasionally unclear.

- **Acquaintance with the methods of research and their application to their investigations:** Satisfactory. The panel felt that more clarity was required about the sampling. The candidate should also think about whether the sample for interviews should be drawn only from those who made mistakes; given the complexity of the questions to be posed to students, study of those who gave correct answers could be illuminating. There should also be some interrogation about whether the study is indeed a longitudinal study or a series of case studies. The issue of learning was identified in the proposal and in the presentation. The panel would like a discussion about the aspect of learning that is being studied. It was assumed that the process of learning was being studied – however the instruments don't reflect any 'interview' with students, whether failing or otherwise. The impression was that students who made mistakes would be 'interviewed' to ascertain where in the proportional reasoning process they went wrong. This is why it was suggested that 'interviewing' successful students to compare their proportional reasoning processes would help to illuminate the phenomenon under study. Note too, that there is no mention of phenomenographic methodology! Please check the format for the consent letters; there are new guidelines for this.
- **Acquaintance with the relevant literature:** Relevant. The panel would like further clarity on the different ways in which 'context' was used in the proposal.
  It was noted that discussion about threshold concepts was minimal and confined to reporting done by Frith and Lloyd. If the notion of threshold concepts is going to inform the analysis, it requires more attention than just a citation from a secondary source. The discussion of liminal space needs a reference.
  The discussion of rigour needs to be treated as a whole not as two separate discussions (quantitative and qualitative) that are unrelated. Details of how Lincoln & Guba's criteria will be met should be given, by going beyond just the listing of the criteria. As a mixed-method study in educational research, we expect more engagement with theoretical issues such as methodology for a mixed-methods study. Is the study indeed mixed-methods or quantitative or qualitative?

- **Potentially assessing the significance of their findings:** Good. The study would add to knowledge in the areas of teaching and learning medical science topics, proportional reasoning in mathematics, as well as in the area of mathematical literacy

- **References and Referencing:** This was done satisfactorily. However the panel noted that key references such as Orrill; Lincoln & Guba were citations. At PhD level in educational research, it is expected that such sources would be engaged as primary references. Please use an updated version of Cohen, Manion & Morrison.

- **Research Schedule (work/plan/time-frame):** Fine overall. It is noted that the schedule shows 'Proposal revision' scheduled for Jan-Jun 2014, and that consideration of the proposal at the beginning of the PhD process would possibly have avoided some of the inconsistencies noted at this stage.

- **(PhD ONLY):** Does it show potential as an original contribution to the field: **Yes**

2. *Decision* (tick one of four choices below)

The proposal is:

Accepted, without any corrections or revisions.	**Accepted, provided corrections and revisions/ extensions** are carried out to the satisfaction of the supervisor. The student will complete a schedule of revisions indicating the changes made. The supervisor to confirm the changes made in writing. The revised proposal must be submitted to the School Postgraduate Administrator for noting at School's Research and Higher Degrees Committee.	Should **not be accepted**, but should be returned to the candidate for substantive revision / extension and then be resubmitted for examination	Should be **rejected** outright.
	√		

ADDITIONAL RECOMMENDATIONS BY PANEL MEMBERS:

- Important references such as Orrill; Meyer & Land; Marton & Booth; Lincoln & Guba should be used as primary sources.
- Clarification on how the notion of 'context' is used in the study
- In terms of rigour, explanations of how the different criteria for quantitative and qualitative methodology will be met.

- Discussion of why the study is considered as mixed-methods by engaging with some theory.
- Discussion of whether it is improvement in performance or the process of learning that will be probed, and a clarification of the instruments that will be used to achieve this.
- Discussion about whether the study is longitudinal or a series of case studies
- Check university guidelines for consent letters and adjust accordingly.

The panel would like to extend their best wishes to the student and supervisor.

Signature of Chairperson: [redacted]

Administrator (Postgraduate and Research) Mbalenhle Ngcobo

1.3 Schedule of revisions

COLLEGE OF HUMANITIES

Schedule of Revisions Completed Post-Proposal Review

Masters/PhD

(Please enumerate and describe, in the form below, the concerns expressed or revisions required by the panel as well as how the concerns/revisions were addressed/effected in the revised proposal. Please add numbers if more are needed.)

Student Name: Catherine Harries

Student Number:871871463

Degree: PhD

Title of Thesis/Dissertation: Investigation into drug dosage practices and proportional reasoning in mathematics among medical students

#	Concern Expressed/Revision Required (verbatim, source, by whom, page reference)	Actions taken (detailed description, new page reference if applicable)
	Acquaintance with the methods of research and their application to their investigations	
1	**Page 1 line 8 "more clarity was required about the sampling"**	Details about the study population for the quantitative and qualitative components of the study was provided (2.7 Research Methods/Approach to study) Phase I quantitative components (heading 'Sampling') (Page 10 line 3) "All students starting the third year of study for two consecutive years…" Phase I qualitative: -Error analysis: "all third year dosage assessment responses (Page 11,14 lines from the bottom) -Observation of one-on-one teaching and learning: 2 samples- selection guided by quantitative component and error analysis. First sample: from students during the third year of study who had omitted questions or made errors where the student's reasoning could not be followed. The sample was stratified across the range of ability of students not demonstrating competence. Second sample: Selection guided by first sample where most variability regarding barriers to progress among weakest students. Invited students scoring 0% in their final third year dosage assessment and observed a convenience sample of those choosing to attend." (Page 11, 13 lines from the bottom)

		Phase II: "all first year students after two terms of proportional reasoning and dosage calculation tuition" (Page 12 , line 1) Phase III: "all first year students after three terms of proportional reasoning and dosage calculation tuition" (Page 12, 11 lines from the bottom)
2	**Page 1 line 9 "..should think about whether the sample for interviews should be drawn only from those who made mistakes; given the complexity of the questions to be posed to students, study of those who gave correct answers could be illuminating" and** **Page 1 line 19 "This is why it was suggested that interviewing successful students to compare their proportional reasoning processes would help illuminate the phenomenon under study"**	A rationale for the sampling is provided under the heading Phase I Qualitative component Study design rationale (2.7 Research Methods/Approach to study) (Page 10, line 13). This includes an explanation as to why the sample has been drawn from only those who make mistakes. See Page 10, 5 lines from the bottom: "For pragmatic reasons successful students were not invited for one-on-one tuition as it would take up students' time without the opportunity for remediating dosing skills as these were already evident. However, selection of students from the range of partial competence would mean that some students experienced a very small barrier to complete competence and would require very little further assistance for them to proceed to full competence. The one-on-one observations would provide the opportunity to compare the characteristics of these more able students with those of the struggling students in order to illuminate attributes associated with success. Successful students were also specifically not selected for observation because this was not expected to offer insight into developmental stages or the way in which students learn so that they progress toward competence. According to the threshold concepts theory, once learned a threshold concept cannot be unlearned (Meyer and Land, 2003)so observation of successful students provides no information about the process of crossing the threshold, and reflection back on this crossing to articulate details about the steps in this process is difficult.(Meyer and Land, 2003). According to sociocultural theory, humans learn best when they are in the ZPD, accomplishing a task that they would not yet manage independently but are able to achieve success when engaged in a collaborative dialogue with a 'More Knowledgeable Other' (John-Steiner and Mahn, 1996). Successful students are able to accomplish the task independently so would no longer be working in the ZPD. Vygotsky focused his attention on learners working at a level slightly above their ability to demonstrate independent competence in order to see how learning develops.

		Accordingly, the focus of observations is the interaction of the teacher guiding students who are not yet independently successful to collaborative demonstration of competence".
3	**"Page 1 line 12 There should be some interrogation about whether the study is indeed a longitudinal study or a series of case studies"**	A discussion about the reason for classifying this study design as longitudinal is included in (2.7 Research Methods/Approach to study) Phase I: Quantitative component Study design rationale (Page 9 , 8 lines from the bottom) "As a starting point…followed over time" and Study design (Page 9, 5 lines from the bottom) "Repeated observations of student progress with respect to different types of dosage calculations (involving differing proportional reasoning skills) were made over time. Students starting the third year of study were given – and took up- a varying set of dosage calculation learning opportunities. Their progress was followed into their fourth year with repeated assessments to see how their exposures affected their outcomes. The study was consequently considered to be longitudinal, rather than a series of case studies where all individuals receive the same intervention or have the same outcome " Also, the one-on-one teaching, while all occurring at one time (after the end of the Third Year assessments) does not give a cross-sectional (snapshot) view but is instead a view of the development of students as they progress through the questions they have found difficult.
4	**"Page 1 line 14 "The panel would like a discussion about the aspect of learning that is being studied. It was assumed that process of learning was being studied**	A paragraph explaining the focus on both process and outcome of learning is included in '2.7 Research Methods/Approach to study' under the heading 'Study design approach'. Page 8, line 9: "Sociocultural researchers emphasize methods which focus on the interaction between participants focusing on a meaningful activity and which document cognitive and social change. Rather than seeing a dichotomy between quantitative and qualitative research, approaches are chosen that emphasize process and development and the multiple ways in which both can be revealed. (John-Steiner and Mahn, 1996). Consequently a multiphase mixed-methods study design has been chosen, with aspects providing a longitudinal view and an opportunity to observe what is revealed during guided participation in tasks requiring proportional reasoning"

		A discussion about the aspects of learning (outcome of learning as well as the process of learning with respect to dosing and proportional reasoning is included in (2.7 Research Methods/Approach to study) Phase I Qualitative component Study design rationale: Page 10, line 18. "Observation of one-on-one teaching interactions would reveal cognitive as well as social and emotional barriers for selected students, as well as providing the opportunity for their voices to be heard. The quantitative data provides information about the demonstration of full competence, a student learning outcome. The qualitative component is aimed first at determining levels of partial competence (also an outcome of learning). Together these outcome aspects of learning are what Vygotsky calls the 'fruits of learning' (Vygotsky,1978). Observing one-on-one interactions is aimed at going beyond studying these 'fruits of learning' to also observe Vygotsky's' buds or flowers of learning', a student's ability to achieve competence during the guided learning process which predicts a students' potential ability, so competence is mapped and development followed as they are guided to success (shifting focus from the outcome to the process of learning).'
5	**The instruments don't reflect any interview with students**	Phase I: There is no in-depth interview, but rather one-on-one observed tuition sessions. A written information sheet and consent form was provided to inform students and start a brief discussion about dosage calculations, together with copies of all the dosage calculations questions answered incorrectly by the student during the third year of study. Each student was given a set of the calculations that he or she had answered incorrectly previously, with space provided for written calculation. The consent forms and dosage calculations were included in Appendices I and II. Students were guided through these questions. Details about the method are provided in the Pythagoras paper published in part fulfilment of Objective 1 (Harries, C., & Botha, J. (2013) Assessing medical students' competence in calculating drug doses. *Pythagoras, 34*(2), Art.#186, 9 pages. http://dx.doi.org/10.4102/pythagoras.v3412.186): page 5 column 2 line 29 "After giving written consent,…before and after this tuition". Students were also asked briefly what they thought might contribute to competence at an earlier stage,

		and what they would like to see done differently in terms of the course in order to improve dosage competence.
6	**There is no mention of phenomenographic methodology**	A phenomenographic method is not being used in this study. A sociocultural approach to learning is being taken. A new paragraph has been included in "2.3 Review of Literature" to reflect this: Page 4, line 7: "In this study, learning is viewed from the sociocultural perspective of Vygotsky,…" to (Page 4, line 18 "... learner's joint attention."). The subsequent paragraph has been reworded to follow on from the discussion of the Vygotskyan perspective. In keeping with a sociocultural stance, where 'contemporary Vygotskian scholars researching cognitive change in classroom learning rely on both experimental and qualitative methods to focus on developmental processes, (John-Steiner & Mah, 1996)', a mixed-methods study design has been adopted, with the qualitative component analysis method involving **exploratory thematic analysis**. Although they share common characteristics, mainly that specific codes or analytic categories are not predetermined but derived from the data, thematic analysis differs from phenomenographic analysis in that the themes and codes arising from thematic analysis are not necessarily 'parsimonious' or related to one another in a (usually) hierarchical way as they are in phenomenography. Themes generated will then be compared with categories emerging from Vygotsky's work (steps in the guiding process) and Lloyd & Frith's threshold concepts framework(2013) (which was developed using a phenomenographic approach) and any other theory the literature reveals that might shed light on underlying processing that could account for the data. The perspective of these researchers will be borrowed and focussed on the data in order to understand it in a similar way to the way the student borrows the perspective of the guide to process calculations requiring reasoning beyond developed capabilities. Our focus was on what was revealed about proportional reasoning during written processing of paper problems and about development of proportional reasoning

		during guided participation. According to the Vygotsky view, learning leads to development of thinking skills and artefacts, which in turn drives new learning. Our study has been designed with this in mind, situated within a real classroom with results at each stage and phase informing changes to the programme so that the setting, direction of enquiry and intervention develops as the researcher gains more understanding of how best to meet student needs..
7	**Please check the format for the consent letters; there are new guidelines for this**	The most recent template for the **Information sheet and consent to participate in research** letter for BREC (who have given ethical approval) was downloaded from the Research link on the UKZN website. Although the letters used (included in Appendix I) comply with these requirements, a new consent letter has been developed from this template and will be used to enrol further participants. This letter has been added to Appendix II and is attached with this submission.
8.	**The panel would like further clarity on the different ways in which context was used in the proposal.**	The final 4 paragraphs of **2.3. Review of Literature** have been rewritten to clarify the different ways context has been considered. From Page 5 line 3 " This evidence of the intricate connection between workplace context and both the acquisition and demonstration of a skill…" to Page 6, line 9 "…in the context of different tasks" In addition, I have included some points on this here: From the Oxford dictionary 'context' is the circumstances that form the setting for an event, statement or idea and in terms of which it can fully be understood. Reasoning proportionally about numerical information is such an'event'. Contextual factors may help or hinder this reasoning. I consider several contextual factors within: -The workplace and compare them to those related to -The learning environment -The assessment -The task **In the context of the workplace**

		Students will face a real patient with a problem that must first be diagnosed before treatment begins. Dosage or risk information will need to be extracted from guidelines or scientific publications. Formulation information will be obtained from strengths or concentrations in labelled containers and measuring information from measuring devices used. **In the context of the learning environment** Learning occurs when a learner and guide work together on a task. The context in which the learning occurs is considered. How are students prepared for the workplace? How do contextual factors differ? How is the task presented compared to what would be expected in the workplace? *Patient information*: As numerical elements within text (e.g. a weight in kilograms or an age)? Or the student as his or her own patient (e.g. would you take this medicine if…) ? -compared to being face-to-face with a real patient in a workplace context *Dosage or treatment risk information*: As elements of a written narrative? Embedded in an excerpt from a guideline? As a graph? As a table? *Formulation information* (for dosage calculation): As elements of a written narrative? From the label of a diagram of a container? *Measuring information and equipment*: not provided? Provided visually as a diagram or graphic? What other perceptual or emotional information must the learner process at the same time as they learn to use proportional reasoning to fulfil a task that might help or hinder processing Does learning occur in a large noisy large-group setting where the student has no control over the pace of the lecture, followed by the opportunity to work through written problems privately and to receive subsequent feedback in the form of an electronically available written model answer and large-group revision session where a teacher and perhaps student volunteers work through problems on the board,

		Does the learning occur after the large group opportunity during an opportunity to process the task in an informal classroom **group tutorial** setting, where there is more noise which may be disruptive or may be processed as 'white noise' which can readily filtered out, many other students working through the questions at the same time might invoke a feeling of solidarity that inspires a student to persevere or might make student fear ridicule, there may be the opportunity to collaborate with a more skilled neighbouring student, perhaps with a common mother tongue that is other than the language of instruction, who can act as a guide, there may be a tutor available to clarify aspects of the task, there may be less pressure to work at speed than might be expected in a work setting Does the learning occur after the large group opportunity in a quiet office in the context of **one-on-one teaching**, where there is less extraneous sound information to filter out than a classroom or work setting, less pressure to work at speed that might invoke anxiety than might be expected in a work setting or formal assessment, no interruptions from other people other than the guide, with a guide who perhaps does not share your mother tongue, possibly pressure from the intimacy of the connection between guide and learner to maintain a positive connection and repair communication breakdowns, an opportunity to communicate dynamically to receive feedback adapted to fit the information as it is provided so that understanding can develop in an appropriate direction? **In the context of the assessment** How is the learner's performance measured? As a true/false question, as a written calculation, as short written responses, as prepared dose? How do contextual factor compare to those in the workplace? To those in the learning environment? Compared with workplace? Compared with learning environment?)

		What other perceptual or emotional information must the learner process at the same time as the numerical processing during the assessment process that might help or hinder processing As part of a formal assessment in silence with a time limit with the requirement to work independently without consulting notes, that might invoke anxiety? In an examination hall or a skills laboratory? For the first time or after several assessments over time? How must the numerical information be presented? Multiple choice selection? As a written figure or as a prepared dose? With size of container and amount of liquid providing contextual clues? Measuring information and equipment Not supplied or supplied as real measuring device with measurement markings comparable to that supplied by the formulation manufacturer. **In the context of the task** The task of dosage calculation is considered and compared to interpreting health risk statistics to make a rational treatment decision. The first task involves proportional reasoning about numbers (e.g. an amount of drug (a number)in a volume of solution(a number))whereas in the context of comparing health risk statistics, students must reason proportionally about percentages (e.g. a change in risk(%) compared with the initial risk(%)). This makes the second task more difficult. Further contextual factors, not yet considered in this study but informing its line of enquiry, would be reasoning about percentages in the context of an advertisement and other company literature where sensory information appealing to subconscious fears and desires to sell its product must be processed and students must reason critically about numerical information and why it has been presented in a particular way.
9	**"Discussion about threshold concepts was minimal and confined to reporting done by Frith and Lloyd. If the notion of threshold concepts is going to inform the analysis, it requires**	Paragraph 2 (Page 4 , line 7) beginning "In this study,…" and ending (Page 4, line 25)" … to proportional reasoning competence" has been included in **2.3. Review of Literature** to clarify my approach. Although the sociocultural perspective will

	more attention than just a citation from a secondary source. The discussion of liminal space needs a reference"	inform my analysis, which consequently will proceed in an exploratory fashion, without being constrained by predetermined specific codes or analytic categories, the categories will be compared to those determined by Lloyd and Frith. Paragraph 1 (Page 3, 3 lines from the bottom) has been revised to discuss threshold concepts more fully and includes a primary source. (Meyer and Land, 2003). The discussion of liminal space has now been referenced.
10	**The discussion of rigour needs to be treated as a whole not as two separate discussions (qualitative and quantitative). Details of how Lincoln and Guba's criteria will be met should be given, by going beyond just the listing of the criteria**	Section 2.8: Validity, reliability, and rigour has been rewritten so that the discussion of rigour is treated as a whole, with details provided as to how Guba's criteria will be achieved within the qualitative and quantitative strands. From (Page 13, line 13): "In order to address rigour I've been guided by Shenton's review of Guba's four constructs (credibility, transferability, dependability and confirmability), as well as the positivist concepts of validity and reliability. Several provisions have been made…" to Page 14 last line "…the context of the reader."
`11	**As a mixed-method study in educational research, we expect more engagement with theoretical issues such as methodology for a mixed-methods study. Is the study indeed mixed-methods or quantitative or qualitative?** Also, under 'additional recommendations by panel members, Page 4 (1st line) **Discussion of why the study is considered as mixed-methods by engaging with some theory**	Is the study mixed-methods? The study is considered to be mixed-methods research because it involves both quantitative and qualitative components or 'strands' that include each of the steps in the process of conducting research, namely posing a question, collection of data, data analysis and interpreting results. (Clark & Creswell; 2011). Why mixed-methods? Cohen and Manion explain that the perspectives of both normative and interpretive approaches are necessary and inseparable aspects of understanding human behaviour and experience and this view is echoed by other authors. (Cohen & Manion, 1980; Neuman, 2000; Entwistle & Ramsden1983). They recommend using mixed quantitative and interpretive methods in order to look at a phenomenon from different perspectives and benefit from the strengths of the different methods. Why multiphase mixed-methods? A multiphase study is appropriate for an emerging mixed-methods study, where new questions arise during different stages of the research project (Bryman,2006). In keeping with sociocultural theory which assumes that learning outcomes (products such as art or inventions or new knowledge) changes the context in which the learning occurred, the research proceeded in phases, with the results of the first phase informing teaching innovations so that the teaching context for subsequent

		student cohorts were changed by these results. The results generated new questions which are explored in second and third phases. The multiphase mixed-methods designs consists of several distinct phases: this study comprises three phases involving distinct student cohorts, with the results from the first phase informing the research questions for the second and third phases. Within each phase, quantitative and qualitative data strands are combined concurrently and sequentially (as shown in fig 1). with results from initial strands informing the design of subsequent strands. In Phase I, the first strand, a qualitative instrument is embedded within the first of a series of quantitative assessments. After this qualitative strand is analysed, it informs the selection of a group of participants for one-on one interaction. Quantitative results inform the selection of a second group of students showing the very poorest proportional reasoning abilities. Analysis of these one-on one teaching interactions lead to a further intervention, group tuition, which encouraged peer teaching and learning and produced quantitative data. In Phase II, qualitative data was embedded within a randomised controlled trial. In Phase III, quantitative data informed the collection of qualitative data to elaborate and clarify quantitative results. Further qualitative data was gathered and analysed, which informed a teaching intervention (and the selection of participants for one-on-one teaching) and further quantitative data collection and analysis. Mixed methods were chosen so that qualitative data would illustrate, clarify and elaborate results from the predominant quantitative method and the quantitative results would inform the selection of participants who had not yet reached the threshold for proportional reasoning so that, if they could be guided across this threshold during one-on –on interaction, this process could be observed and characterised.

12	**Key references such as Orrill; Lincoln and Guba were citations… it is expected that such sources would be engaged as primary references**	**Orril** This was the author of the preface for the Steen reference. The reference has been corrected according to the APA 6th Edition style guidelines for the author of a preface for the book by a different author as follows: **Orrill, R.**,(2001). [Preface]. In L.A. Steen, *Mathematics and Democracy: Case for Quantitative Literacy* (p. xviii). USA: National Council on Educations and the Disciplines. **(Lincoln and) Guba** The primary source has been cited in the proposal and included in the references. **Guba, E.G.** (1981) Criteria for assessing the trustworthiness of naturalistic enquiries. *Educational Communication and Technology Journal*, 29, 75-91.
13	**Please use an updated version of Cohen, Manion and Morrison**	The original reference (Cohen & Manion, 1980) was updated to the 7th Edition as follows **Cohen, L., Manion, L. & Morrison** (2011). *Research Methods in Education.* (7th Edition) New York: Routledge.
14	**Important references such as… Meyer & Land; Marton & Booth…should be used as primary sources**	The primary sources have been cited and included in the references. **Meyer, J.H.F & Land, R.** (2003). Threshold concepts and troublesome knowledge (I): linkages to ways of thinking and practicing, in Rust, C. (ed). Improving student learning- ten years on. Oxford: OCSLD. **Marton, F., & Booth, S. A.** (1997). *Learning and awareness*. Psychology Press.

1.4 Revised Proposal

8 February 2015

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

COLLEGE OF HUMANITIES

MASTERS/PHD RESEARCH PROPOSAL AND ETHICAL CLEARANCE APPLICATION (HUMAN AND SOCIAL SCIENCES)

PLEASE NOTE THAT THE FORM MUST BE COMPLETED IN TYPED SCRIPT. HANDWRITTEN APPLICATIONS WILL NOT BE CONSIDERED

SECTION 1: PERSONAL DETAILS

1.1	**Full Name & Surname of Applicant :**		Catherine Sara Harries
1.2	Title (Ms/ Mr/ Mrs/ Dr/ Professor etc)	:	Mrs
1.3	Applicants gender	:	female
1.4	Applicants Race (African/ Coloured/Indian/White/Other)	:	White
1.5	**Student Number** (where applicable)	:	871871463
	Staff Number (where applicable)	:	800528
1.6	School	:	School of Education
1.7	College	:	College of Humanities
1.8	Campus	:	Edgewood
1.9	Existing Qualifications	:	BSc(pharm); PGDip(higher ed); MMedSci(pharmacol); MEd(higher ed)
1.10	Proposed Qualification for Project (In the case of research of degree purposes)	:	PhD

2. Contact Details

Tel. No.	:	(031)3031833 (h); (031)2604337 (w)
Cell. No.	:	0832312761
e-mail		harriesk@ukzn.ac.za

Postal address (in the case of students and external applicants)	: 39 Rapson Road, Morningside, Durban, 4001

Proposal for:

PhD Thesis:	100% 100 000 words	384 credits	□
Dissertation	100% 40 000 words	192 credits	□
Coursework Dissertation	66.6% 28 000 words	128 credits	□
Short Dissertation	50%) 20 000 words	96 credits	□
Treatise	33.3% 14 000 words	64 credits	□

In the case of coursework degree, provide a brief description of degree programme:
(e.g., nature of degree, number and names of modules passed)

Each research proposal should be submitted together with a fully completed

- *Contract between Supervisor and Candidate.*

We are satisfied with the academic merit and viability of the proposal and research project, subject to ethical clearance:

2 Supervisor:

Name:.....Signature:.....Date:.....
.....

2. Academic Leader (Discipline):

Name:.....Signature:.....Date:.....
.....

3. Academic Leader (Research)

Name:.....Signature:.....Date:.....
.....

3. SUPERVISOR/ PROJECT LEADER DETAILS

NAME	TELEPHONE NO.	EMAIL	DEPARTMENT / INSTITUTION	QUALIFICATIONS
3.1 Prof Julia Botha	(031)2604337	BOTHA@ukzn.ac.za	School of Health Sciences, College of Health Sciences	PhD
3.2 Prof Renuka Vithal	(031)2602988	vithalr@ukzn.ac.za	Teaching and Learning	PhD

SECTION 2: PROJECT DESCRIPTION

2. 1. Project title (40 words)

(Give a short title, be specific, include key terms)

Investigation into drug dosage practices and proportional reasoning in mathematics among medical students.

2.2. Brief motivation/Background (200 words)

The numerate individual uses quantitative skills to understand the varied settings of the world (Orrill 2001, p.xviii), including the workplace. A definitive case statement has been developed, listing behaviours, and their underpinning skills, involving this kind of thinking, which is also called quantitative or mathematical literacy (Steen, 2001). Those relevant to clinicians treating patients include rational drug selection, helping patients understand different treatment option risks, and administering drugs in an appropriate amount and rate. Rational prescribing depends on an understanding of different ways of representing risk: ratio concepts which include risk ratios, absolute and relative risk, and the 'number of patients needed to treat', abbreviated as NNT (Therapeutics Letter Working Group, 1996). Communicating treatment option risks to patients involves an understanding of how these different risk representations may influence the patient's choice of treatment and an ability to represent risk in different ways to assist a patient in making sense of the numbers. Dosage calculations of drugs in solution require an understanding of an intensive quantity, concentration, which relates the mass of a drug in solution to the volume of the solution. The drug concentration may be represented in either a mass/volume format, as a ratio or as a percentage. Choosing an appropriate rate at which drugs to be administered by infusion are given is dependent on another intensive quantity: flow rate.

2.3. Review of Literature (400 words)

(Outline previous work/literature relevant to your study, who are the main thinkers/researchers/protagonists in the area? Please do not provide long annotations but demonstrate a broad awareness of the body of literature that exists on your topic. Show where there are gaps and limitations in current research and how this study will seek to make a contribution to the academic debate)

Proportional reasoning, a key arithmetic skill (Steen, 2001), underlies the numerical skills of drug therapy. Proportional reasoning is thought of as a 'threshold concept' (Frith and Lloyd, 2013), a term developed by Meyer and Land (2003) to describe certain key concepts which act as a gateway to full competence. Such concepts are transformative, irreversible, integrative and involve 'troublesome knowledge', which conflicts with older forms of understanding. As students grapple with new counterintuitive thinking, they must proceed through an uncomfortable transitional state (called the liminal space). Prior to this stage, students are in a preliminal stage of understanding. Students within the liminal space may engage with the new understanding in ways that include mimicry and lack authenticity. Learners can remain suspended in this state or emerge with a transformed understanding.

In this study, learning is viewed from the sociocultural perspective of Vygotsky (1978), where understanding occurs first as a social interaction between a learner and a guide (a more skilled individual) while working together performing a meaningful task, and subsequently in the individual as an internal dialogue (John-Steiner and Mahn,1996). According to this view, a teacher would ideally provide just sufficient scaffolding (such as collaborative dialogue) to ensure that students remain beyond their current level of development but within their zones of proximal development (ZPD), (the distance between their current level of development as determined by independent problem solving, and their level of potential ability as determined through problem-solving under expert guidance). Vygotsky observed how students tried to satisfy task requirements that were just beyond their reach, as this offered insight into the normally hidden processes underlying the beginnings of new skills. This focus assisted him in determining strategies that could be offered to assist struggling students to move to the outer limit of their ZPD. For him, performance level was most useful for providing information about what sort of task should be the next focus of the guide and learner's joint attention (John-Steiner and Mahn,1996). Threshold concepts theory fits well with this approach as Vygotsky views learning as a qualitative transformation that occurs during social or internal dialogues. Vygotsky's scientific enquiry involved a dialectic approach, which views phenomena as syntheses of contradictions. The dialectic approach fits well with the imagery of moving through the liminal space of a threshold concept to emerge with a transformed understanding. Using the language of the sociocultural perspective and threshold concept theory, this study involves

how best to guide students, within their ZPD through the liminal space and across the threshold to proportional reasoning competence.

Because medical students have achieved in school mathematics, a requirement (UKZN website) for a fiercely contested place in medical school, and mathematics taught in school has been thought to transfer to the mathematics encountered outside school (Stasz, 2001), students have been expected to have proportional reasoning skills that can readily be transferred to the clinical setting. However, school mathematics success does not necessarily guarantee numeracy in the workplace. Research suggests that mathematical knowledge transfer does not happen readily (Stasz, 2001). Steen (2001) explains that mathematics becomes increasingly abstract. The disconnect between written assessment and workplace skills goes further, as revealed in recent ethnological studies of mathematics in the workplace, where for example, nurses who may be unable to perform drug dosage calculations on paper may demonstrate drug dosing competence in the ward., employing different reasoning strategies to do so (Hoyles, Noss & Pozzi, 2001; Stasz, 2001).

This evidence of the intricate connection between workplace context and both the acquisition and demonstration of a skill have implications for the acquisition and assessment of proportional reasoning. The importance of contextual factors during the learning interaction is recognized from the sociocultural perspective as factors which would assist students attain or remain within the ZPD or those which disrupt or prevent or student learning within the ZPD. Consequently sensory factors such as environmental noise, emotional factors such as anxiety-inducing situations, relationship and communication factors such as the level of responsivity that a type of teaching interaction can accommodate and the speed and quality of the feedback that can be given affect a student's location within the ZPD.

With the sociocultural recognition of the importance of engaging with authentic tools and tasks (while still maintaining the task within the ZPD), it would be expected that students would acquire proportional reasoning skills transferable to the workplace when these are learned during exposure to as many authentic components of a task as can be achieved within the limits of ethical considerations and the constraints of the classroom. The extent to which authentic contextual factors relevant to the workplace are included in an assessment would affect its relevance to workplace numeracy.

Though Vygotsky's guide is in a position of greater power, he assumes the guide has the learner's best interests at heart. Through being responsive, the guide ensures the learner's voice is not ignored. However, detrimental learning can also occur when a faulty guide abuses the position of trust and power leading to processing and products that are not mutually beneficial. Critical learning theory focuses on how power relationships influence learning.. Habermas (1971) categorises knowledge as instrumental (technical human interests associated with work), practical (interpreted through everyday social activites) and emancipatory (recognizing the role of power and control in the way knowledge is shaped) Critical theory seeks to generate emancipatory forms of knowledge to provide alternative and progressive ways of looking at the world. Vithal (2012) argues that the mathematically literate individual should be one who is empowered to go beyond functional literacy to ask why the numbers have been formatted in a particular way, how the chosen format serves the producers of the figures, and how the numbers would be interpreted if they were formatted in a different way. Clinicians must use this kind of thinking to assess numerical risk information in order to guide a patient in making the most appropriate treatment choice, bearing in mind that this is not the primary goal of the producers of the figures. Among law and humanities students, difficulties with proportional ratio concepts impeded the development of their ability to reason critically about quantitative information. (Lloyd and Frith, 2013) The level of difficulty of proportional reasoning is dependant on the task context in which it is being used. During dosage calculation is students are required to reason proportionately about numbers (e.g. an amount of drug (a quantity) in a volume of solution(a quantity))whereas in the more difficult context of comparing health risk statistics, students must reason proportionally about percentages (e.g. a change in risk(%) compared with the initial risk(%)) as well as reasoning critically about why figures have been presented in the way that they have, and what form of presentation will best serve (and emancipate) the patient. This makes the second task more difficult.

Consequently the present study will add to the literature by looking at the ability of medical students to benefit from different learning contexts to show proportional reasoning skills in settings that contain varying amounts of workplace-related factors and in the context of different tasks.

2.4. Location of the Study (For Empirical Studies Only) (100 words)

(Geographic – spatial, Temporal – time period, Social – socio-political-economic context)

Dosage error remains an important source of morbidity and mortality worldwide (Lewis et al., 2009; Simpson, Gerben, and Lind, 2009) and irrational prescribing is associated with suboptimal treatment and unnecessary health risks and costs (De Vries, Henning, Hogerzeil & Fresle, 1994; Hogerzeil *et al.*2001). Among doctors, clinicians in Australia are less competent at dosing than they believe they should be (Simpson, Gerben, and Lind, 2009). Difficulty with ratio concepts accounts for most suboptimal mathematical proficiency and predicts poorer health outcomes in the USA (Reyna and Brainerd, 2007).

Such difficulties also cause medical students to struggle with drug dosage calculations when the concentration is expressed as a ratio or percentage (Wheeler, Remoundos, Whittlestone, House, & Menon, 2004). Drug dosing has also been alluded to as a problem among South African medical students (Harries, Mbali, & Botha, 2006), but the extent and nature of the problem is not known. For law and humanities students at university, proportional reasoning is a threshold concept for numeracy and critical thinking that very few students have reached (Lloyd and Frith, 2013). Our papers will be the first to investigate proportional reasoning among South African medical students.

2.5. Objectives

(Set out the major objectives/aims of the study State these explicitly e.g:)
"The objectives of this study are:

4. To ....
5. To...
6. To...

This research will explore the nature of proportional reasoning skills demonstrated, and the effect of contextual factors, when medical students are engaged in different tasks typical of those that will be encountered during the provision of drug therapy for patients.

The thesis will be by publication and the measurable outcomes will be these publications. In these the aim is to achieve the following:

Objective 1. To investigate the nature of the proportional reasoning knowledge and skills medical students demonstrate when calculating drug doses from paper problems after exposure to different learning contexts.

Publication 1: Harries, C., & Botha, J. (2013) Can medical students calculate drug doses? *South African Journal of Anaesthesia and Analgesia, 19*(5):248-251

Publication 2: Harries, C., & Botha, J. (2013) Assessing medical students' competence in calculating drug doses. *Pythagoras, 34*(2), Art.#186, 9 pages. http://dx.doi.org/10.4102/pythagoras.v3412.186

Objective 2. To investigate the nature of students' ability to do proportional reasoning in the workplace-related contexts of:

i) needing to extract embedded information from guidelines in relation to calculating drug doses.

ii) needing to actually manipulate the syringes and formulations to prepare the drug dosage for parenteral administration

Publication 3: To be submitted to the journal Educational Studies in Mathematics.

Objective 3. Investigate the nature of students' ability to show their proportional reasoning knowledge and skills in the context of assessing data that gives drug therapy risk/benefit information.

Publication 4: submit paper to Medical Education Journal

2.6. Questions to be Asked

(Set out the critical questions which you intend to answer by undertaking this research –these must be directly correlated to the objectives)

Research Question 1.

What is the nature of the proportional reasoning skills medical students demonstrate when calculating drug doses from paper problems after exposure to different learning contexts? When students are supplied with the appropriate numerical values, how do they fare in paper and pencil assessments? Do they improve with time and practice, group or one-on-one tuition? What is the nature of the proportional reasoning demands underlying the different kinds of calculation and which are most problematic?

Research Question 2.

What role do drug dosage contextual factors in assessment play in students' ability to demonstrate proportional reasoning skills? How do skills compare when contextual factors relevant to the demands of the workplace are increasingly included in the assessment? How do students fare in written assessments when extracts from guidelines are provided and their embedded numerical values must be extracted in order to calculate drug doses. How does this compare with a situation where they must not only consult guidelines and package inserts, to find the relevant dosage information, but must also actually manipulate the syringes and formulations in performance assessments to prepare the drug for parenteral administration?

Research question 3.

What is the nature of students' ability to show their proportional reasoning knowledge and skills when performing a drug therapy task demanding critical thinking? How does this compare with the proportional reasoning skills they show with the less cognitively demanding task of dosing drugs? According to threshold concepts theory, have students crossed the threshold to a deeper way of understanding risk statistics and the percentage change they describe? If not, at what stage are they in developing these skills?

2.7. Research Methods / Approach to Study (400 words)

(Explain *how* you will go about answering the main research questions and the approach within which you will work. Describe the design of the study, sampling and sampling method with rationale, data collection methods, data analysis methods - be specific)
In **Appendix One** you are required to attach copies of all your **'instruments'**: questionnaires; discussion outlines, interview schedules/questions; coding sheets etc.

Study design approach:

Sociocultural researchers emphasize methods which focus on the interaction between participants focusing on a meaningful activity and which document cognitive and social change. Rather than seeing a dichotomy between quantitative and qualitative research, approaches are chosen that emphasize process and development and the multiple ways in which both can be revealed (John-Steiner and Mahn, 1996). Consequently a multiphase mixed-methods study design has been chosen, with aspects providing a longitudinal view and an opportunity to observe what is revealed during guided participation in tasks requiring proportional reasoning

Cohen, Manion & Morrison explain that the perspectives of both normative and interpretive approaches are necessary and inseparable aspects of understanding human behaviour and experience and this view is echoed by other authors. (Cohen, Manion & Morrison, 2011;

Neuman, 2000; Entwistle & Ramsden1983). They recommend using mixed quantitative and interpretive methods in order to look at a phenomenon from different perspectives and benefit from the strengths of the different methods.

Study design:

Multiphase mixed-methods (see fig 1)

The research will be conducted in sequential phases (Clark and Creswell, 2011) each with a different cohort of students, with phases I, II and III aimed at answering research questions 1,2 and 3 respectively. Phasing has been chosen for pragmatic reasons, as well as because the results of phase I inform the research questions asked in phases II and III A multiphase study is considered appropriate for an emerging mixed-methods study, where new questions arise during different stages of the research project. (Bryman, 2006). A mixed-methods study design would provide greater insight than either type by itself, and quantitative results would inform the selection of study participants for some of the qualitative work, while qualitative results would elaborate and provide clarity to the results generated by quantitative methods.

Phase I

Mixed-methods:

Study design: qualitative strand embedded within quantitative strand → two qualitative strands→ quantitative strand all embedded within a larger quantitative study

In Phase 1, the first strand, a qualitative instruments is embedded within the first of a series of quantitative assessments. After this qualitative strand is analysed, it informs the selection of a group of participants for one-on one interaction. Quantitative results inform the selection of a second group of students showing the very poorest proportional reasoning abilities. Analysis of these one-on one teaching interactions lead to a further intervention, group tuition with opportunities for peer teaching and learning and produced quantitative data. All the quantitative data is used to provide a longitudinal view of cumulative demonstration of ability for each student.

Quantitative components:

Study design rationale: As a starting point for exploring the proportional ability students demonstrate, and in order to separate what competence they bring to medical school from what

they develop at medical school, student progress with respect to different types of dosage calculations was followed over time.

Study design: longitudinal before-after study

Repeated observations of student progress with respect to different types of dosage calculations (involving differing proportional reasoning skills) were made over time. Students starting the third year of study were given – and took up- a varying set of dosage calculation learning opportunities. Their progress was followed into their fourth year with repeated assessments to see how their exposures affected their outcomes. The study was consequently considered to be longitudinal, rather than a series of case studies where all individuals receive the same intervention or have the same outcome.

Sampling: all students starting the third year of study for two consecutive years

Analysis: Assessment responses to calculation questions were entered in an Excel® 2007 spreadsheet. Students displaying competence (determined as getting all calculation types right in a single assessment) were determined as well as the potential proportion of patients harmed (the number of mistakes made relative to the number of calculation opportunities). The calculation of descriptive and inferential statistics (including mean and range, and Chi-squared testing) using Epi-Info (Version3.4.3) were included in the analysis. Epi-Associations between some of the different teaching interventions received and subsequent outcomes were sought.

Qualitative components:

Study design rationale:

An important goal of this qualitative component is to understand the different ways in which students reason proportionally that contributes to lack of demonstration of full dosing competence. An analysis of the reasoning visible in the written calculations performed during the quantitative component would reveal some barriers, so it would often be possible to see where students might be going wrong this way. However, this does not provide students an opportunity to confirm or deny this reasoning. Also, for students who do not write down the steps or leave out questions it is not possible to follow their reasoning. Observation of one-on-one teaching interactions would reveal cognitive as well as social and emotional barriers to be revealed for selected students, as well as providing an opportunity for their voices to be heard. The quantitative data provides information about the demonstration of full competence, a student learning outcome. The qualitative component is aimed first at determining levels of partial competence (also an outcome of learning). Together these outcome aspects of learning

are what Vygotsky calls the 'fruits of learning' (Vygotsky,1978). Observing one-on-one interactions is aimed at going beyond studying the 'fruits of learning' to also observe Vygotsky's' buds or flowers of learning', a student's ability to achieve competence during the guided learning process which predicts a students' potential ability, so competence is mapped and development folllowed as they are guided to success (shifting the focus from the outcome to the process of learning).

For pragmatic reasons successful students were not invited for one-on-one tuition as it would take up students' time without the opportunity for remediating dosing skills as these were already evident. However, selection of students from the range of partial competence would mean that some students experienced a very small barrier to complete competence and would require very little further assistance for them to proceed to full competence. The one-on-one observations would provide the opportunity to compare the characteristics of these more able students with those of the struggling students in order to illuminate attributes associated with success. Successful students were also specifically not selected for observation because this was not expected to offer insight into developmental stages or the way in which students learn so that they progress toward competence. According to the threshold concepts theory, once learned a threshold concept cannot be unlearned (Meyer and Land,2003), so observation of successful students provides no information about the process of crossing the threshold, and reflection back on this crossing to articulate details about the steps in this process is difficult . (Meyer and Land, 2003). According to sociocultural theory, humans learn best when they are in the ZPD, accomplishing a task that they would not yet manage independently but are able to achieve success during collaborative dialogue with a 'More Knowledgeable Other' (John-Steiner and Mahn, 1996). Successful students are able to accomplish the task independently so would no longer be working in the ZPD. Vygotsky focused his attention on learners working at a level slightly above their ability to demonstrate indiependant competence in order to see how learning develops. Accordingly, the focus of our observations is the interaction of the teacher guiding students who are not yet independently successful to collaborative demonstration of competence.

Study design:

-Analysis of written calculation assessment responses: error types categorised

-Observation of dialogue and actions during one-on-one teaching and learning interaction while focussed on remediating calculations previously done incorrectly.

Sampling:

-Error analysis: all third year dosage assessment responses

-Observation of one-on-one teaching and learning: 2 samples- selection guided by quantitative component and error analysis. First sample: from students during the third year of study who had omitted questions or made errors where the student's reasoning could not be followed. The sample was stratified across the range of ability of students not demonstrating competence. Second sample: Selection guided by first sample where most variability regarding barriers to progress among weakest students. Invited students scoring 0% in their final third year dosage assessment and observed a convenience sample of those choosing to attend.

Analysis approach: sociocultural

Analysis method: exploratory thematic analysis to find key themes using using QSR NVivo 8, a software package for qualitative data analysis (QSR International, 2008). Themes include those topics relevant to a sociocultural approach

Phase II

Mixed-methods:

Study design: qualitative strand embedded within a quantitative design chosen for pragmatic reasons

Sampling: all first year students (within a cohort following curricular changes informed by Phase I research) after two terms of proportional reasoning and dosage calculation tuition

Quantitative component

Approach: normative

Study design: randomised controlled trial comparing ability demonstrated with paper problem assessment (with relevant numerical data provided) to success with paper problem assessment when guideline provided with embedded numerical information, to success when ability demonstrated by measuring out dose either with numerical data provided or when embedded information must be retrieved from a guideline

Analysis: associations to be sought using Epi Info

Qualitative component

Approach: sociocultural perspective

Study design: analysis of written calculation assessment responses: error types categorised

Analysis approach: sociocultural, threshold concepts theory

Analysis method: exploratory thematic analysis to find key themes including those relevant to a sociocultural approach and to threshold concepts theory using QSR NVivo 8, (QSR International, 2008)

Phase III

Mixed-methods:

Study design: qualitative strand embedded within a quantitative design chosen for pragmatic reasons →qualitative exploratory strand → quantitative strand

Sampling: all first year students (within a cohort following curricular changes informed by Phase I research) after three terms of proportional reasoning and dosage calculation tuition

Quantitative component

Approach: normative

Study design: longitudinal uncontrolled case series comparing ability to interpret health risk statistics to make a rational prescribing decision and to interpret and manipulate different representations of health risk before and after health risk statistics teaching

Analysis approach: normative

Analysis method: associations to be sought using Epi Info

Qualitative component

Approach: sociocultural perspective

Study design:

-Analysis of written calculation assessment responses: error types categorised

-One-on-one teaching and learning interaction with selected students not demonstrating rational treatment selection or accurate interpretation of health risk information

Analysis approach: sociocultural, threshold concepts theory

Analysis method: exploratory thematic analysis to find key themes including those relevant to a sociocultural approach and to threshold concepts theory using QSR NVivo 8, (QSR International, 2008)

2.8. Validity, Reliability and Rigour: 400 words (in the case of empirical research)

(Provide a brief account of the validity and rigour of your study predicated on your theoretical/methodological approach. What are the limitations of your study?)

In **Appendix Two** illustrate how informed consent is to be achieved by providing a copy of an **informed consent** form (including translations if appropriate).

In order to address rigour I've been guided by Guba's (1981) four constructs (credibility, transferability, dependability and confirmability), as these are interpreted by Shenton (2004), as well as the positivist concepts of validity and reliability.

Several provisions have been made to address whether my study measures what is intended (measured by internal validity and credibility for quantitative and qualitative research respectively). The **first is triangulation**. Trustworthy conclusions are drawn when a phenomenon is viewed from different perspectives, and from integrating the meaning of these different aspects. (Shenton, 2004). The mixed-methods dosage study design allows ability within different contexts to be viewed from different aspects. Like comparing class photographs of the same group over time, the quantitative longitudinal component of the research assessment review allows observation of changes (in demonstrating success of written dosage calculation problems) at several points during the course of the programme. The qualitative dosage research offers an in-depth look at firstly an even spread of our students and, second, a group of the weakest students as their competence unfolds. like growth viewed in two different groups of accelerated motion videos. The randomised controlled trial allows tasks requiring dosage skills (demonstrating a skill in two different ways given different contextual information) to be compared when workplace contextual aspects are included to different degrees and assessment is measured in different ways. The final view is provided by viewing proportional reasoning in the context of the new, more difficult skills: of making a rational treatment decision based on assessing health risk information and reformatting this information in different ways. Shenton (2004) also views the use of a wide range of informants as a form of triangulation. The two studies of one-on-one interaction have been designed with this in mind to obtain the greatest diversity of incorrect reasoning processes so that the guided remediation process can be viewed from each of these starting points.

The **second provision** involves **selection** of participants that are most likely to be representative of the study population (medical students involved in proportional reasoning

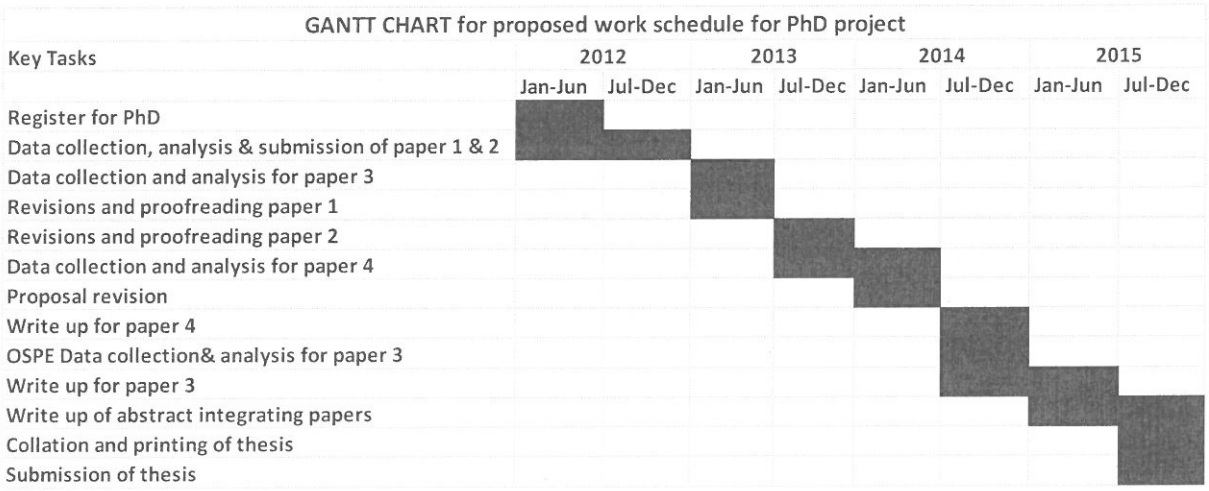
tasks). For the longitudinal component, all Third Year students were enrolled in the study, over two consecutive years to minimise possible period effect. For the randomised controlled trial and health risk statistic assessment, all First Year students for a purposively selected year were invited to participate. For the first qualitative study, a sample of all students who had yet to demonstrate competence successfully was stratified according to error type and number of errors to ensure that smaller groups of interest were represented but that within these groups selection was likely to be representative of the population. Within each group randomised sampling was made to maximise the chance that the sample represented the population from which it was drawn. For the second qualitative study all students not demonstrating any ability were invited for one- on-one tuition in an effort to observe the diversity of this group as well as maintain representivity. It is possible, though that those who chose to attend the lecture are different from those who did not attend and therefore not representative of the full range of problematic reasoning processes.

Additional credibility-strengthening processes, have been the **frequent debriefing sessions** with research supervisors and colleagues and **peer scrutiny of the research project** which has occurred during the research paper publication process, during PhD cohort supervision presentations, as well as during this proposal defence process. **Member checks,** where the meaning understood from what a participant communicates is verified with the participant, is an ongoing part of one-on-one teaching as meaning is clarified so that misconceptions can be diagnosed and the guide can determine what the most appropriate next step will be in the guiding process. **Thick description of the phenomenon under scrutiny** has been provided by the illustration of key categories using real qualitative examples, allowing the reader to judge how well the categories fit with the actual situations.

To address the applicability of study findings to other settings and a wider population I have aimed to **provide sufficient contextual information** to allow readers to determine whether the research may be applied to their context. The reader must make transferability inferences as the researcher does not know the context of the reader.

2.9. Proposed work plan

(Set out your intended plan/timetable of work for the research, indicating important target dates necessary to meet your proposed deadline as agreed with your supervisor).



2.10. Cost Estimate

(Provide a working budget for your research)

Not applicable

2.11. Anticipated Problems/Limitations

(What problems may occur with your project, and how would you deal with them? Logistical/ethical/theoretical)

2.12. References

(Provide a list of references. Keep to the 'house style' of your School: Psychology – APA; History –
Footnotes, Others – Harvard).

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SECTION 3: ETHICAL ISSUES

The UKZN Research Ethics Policy applies to all members of staff, graduate and undergraduate students who are involved in research on or off the campuses of University of KwaZulu-Natal. In addition, any person not affiliated with UKZN who wishes to conduct research with UKZN students and / or staff is bound by the same ethics framework. Each member of the University community is responsible for implementing this Policy in relation to scholarly work with which she or he is associated and to avoid any activity which might be considered to be in violation of this Policy.

All students and members of staff must familiarize themselves with AND sign an undertaking to comply with the University's "Code of Conduct for Research".

QUESTION 3.1

Does your study cover research involving:	YES	NO
Children		
Persons who are intellectually or mentally impaired		
Persons who have experienced traumatic or stressful life circumstances		
Persons who are HIV positive		
Persons highly dependent on medical care		
Persons in dependent or unequal relationships		
Persons in captivity		
Persons living in particularly vulnerable life circumstances		

If "Yes", indicate what measures you will take to protect the autonomy of respondents and (where indicated) to prevent social stigmatisation and/or secondary victimisation of respondents. If you are unsure about any of these concepts, please consult your supervisor/ project leader.

QUESTION 3.2

Will data collection involve any of the following:	YES	NO
Access to confidential information without prior consent of participants		
Participants being required to commit an act which might diminish self-respect or cause them to experience shame, embarrassment, or regret		
Participants being exposed to questions which may be experienced as stressful or upsetting, or to procedures which may have unpleasant or harmful side effects		
The use of stimuli, tasks or procedures which may be experienced as stressful, noxious, or unpleasant		
Any form of deception		

If "Yes", explain and justify. Explain, too, what steps you will take to minimise the potential stress/harm.

QUESTION 3.3

Will any of the following instruments be used for purposes of data collection:	YES	NO
Questionnaire		
Survey schedule		
Interview schedule		
Psychometric test		
Other/ equivalent assessment instrument		

If "Yes", attach copy of research instrument. If data collection involves the use of a psychometric test or equivalent assessment instrument, you are required to provide evidence here that the measure is likely to provide a valid, reliable, and unbiased estimate of the construct being measured. If data collection involves interviews and/or focus groups, please provide a list of the topics to be covered/ kinds of questions to be asked.

QUESTION 3.4

Will the autonomy of participants be protected through the use of an informed consent form, which specifies (in language that respondents will understand):	YES	NO
The nature and purpose/s of the research		
The identity and institutional association of the researcher and supervisor/project leader and their contact details		
The fact that participation is voluntary That responses will be treated in a confidential manner		
Any limits on confidentiality which may apply		
That anonymity will be ensured where appropriate (e.g. coded/ disguised names of participants/ respondents/ institutions)		
The fact that participants are free to withdraw from the research at any time without any negative or undesirable consequences to themselves		

The nature and limits of any benefits participants may receive as a result of their participation in the research		
Is a copy of the informed consent form attached?		

If not, this needs to be explained and justified, also the measures to be adopted to ensure that the respondents fully understand the nature of the research and the consent that they are giving.

QUESTION 3.5

Specify what efforts been made or will be made to obtain informed permission for the research from appropriate authorities and gate-keepers (including caretakers or legal guardians in the case of minor children)?

QUESTION 3.6

STORAGE AND DISPOSAL OF RESEARCH DATA: Please note that the research data should be kept for a period of at least five years in a secure location by arrangement with your supervisor.
How will the research data be disposed of? Please provide specific information, eg shredding of documents incineration of videos, cassettes, etc.

QUESTION 3.7

In the subsequent dissemination of your research findings – in the form of the finished thesis, oral presentations, publication etc. – how will anonymity/ confidentiality be protected?

QUESTION 3.8

Is this research supported by funding that is likely to inform or impact in any way on the design, outcome and dissemination of the research?	YES	NO

If yes, this needs to be explained and justified.

QUESTION 3.9

Has any organisation/company participating in the research or funding the project, imposed any conditions to the research? YES/NO

If yes, please indicate what the conditions are.

SECTION 4: FORMALISATION OF THE ETHICS APPLICATION

APPLICANT

I have familiarised myself with the University's Code of Conduct for Research and undertake to comply with it. The information supplied above is correct to the best of my knowledge.

NB: PLEASE ENSURE THAT THE ATTACHED CHECK SHEET IS COMPLETED

.....

.....

SIGNATURE OF APPLICANT

DATE

SUPERVISOR

NB: PLEASE ENSURE THAT THE APPLICANT HAS COMPLETED THE ATTACHED CHECK SHEET AND THAT THE FORM IS FORWARDED TO YOUR SCHOOL ETHICS COORDINATOR FOR FURTHER ATTENTION

DATE: .....

SIGNATURE OF SUPERVISOR/ PROJECT LEADER

:_____

RECOMMENDATION OF SCHOOL ETHICS COORDINATOR

The application is (please tick):

	Approved *
	Recommended and referred to the Human and Social Sciences Ethics Committee for further consideration
	Not Approved, referred back for revision and resubmission

* Senate has delegated powers to School Committee to:

- Approve Undergraduate and Honours projects
- Approve Masters projects (if the required capacity exists within the School)
- Approve PhD projects (if the required capacity exists within the School)

NAME OF CHAIRPERSON:

_____SIGNATURE:_____

DATE .....

RECOMMENDATION OF SCHOOL RESEARCH ETHICS COMMITTEE
NAME OF CHAIRPERSON:_____SIGNATURE_____ _____ DATE.....

UNIVERSITY OF KWAZULU-NATAL
RESEARCH OFFICE
COLLEGE OF HUMANITIES

CHECK SHEET FOR APPLICATION

PLEASE TICK

1. Form has been fully completed and all questions have been answered	
2. Questionnaire attached (where applicable)	
3. Informed consent document attached (where applicable)	
4. Approval from relevant authorities obtained (and attached) where research involves the utilization of space, data and/or facilities at other institutions/organisations	
5. Signature of Supervisor / project leader	
6. Application forwarded to School Ethics Coordinator for recommendation and transmission to the Research Office	

2. Ethics and Consent

1. Ethics approval letter

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI
RESEARCH OFFICE
BIOMEDICAL RESEARCH ETHICS ADMINISTRATION
Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604769 - Fax: 27 31 2604609
Email: BREC@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx

14 March 2019

Prof. J Botha
Dept. of Therapeutics and Medicines Management
Nelson R. Mandela School of Medicine
University of KwaZulu- Natal

Dear Prof Botha

PROTOCOL: Medical students' abilities to prescribe appropriate drugs and their correct doses. REF: BE185/G9

RECERTIFICATION APPLICATION APPROVAL NOTICE

Approved: 20 January 2019
Expiration of Ethical Approval: 19 January 2020

I wish to advise you that your application for Recertification received on 19 February 2019 for the above protocol has been noted and approved by a sub-committee of the Biomedical Research Ethics Committee (BREC) for another approval period. The start and end dates of this period are indicated above.

If any modifications or adverse events occur in the project before your next scheduled review, you must submit them to BREC for review. Except in emergency situations, no change to the protocol may be implemented until you have received written BREC approval for the change.

The committee will be notified of the above approval at its next meeting to be held on 09 April 2019.

Yours sincerely

[redacted]

Prof V Rambiritch
Chair: Biomedical Research Ethics Committee

cc: harriesk@ukzn.ac.za

2. Sample Consent form for written responses

DIVISION OF PHARMACOLOGY
SCHOOL OF HEALTH SCIENCES
COLLEGE OF HEATH SCIENCES
DATE

Dear students

Our department is looking at the best way to help students become competent prescribers and one aspect of this involves being able to use mathematics to make prescribing decisions and dose medicines. We would like to ask you to please help us revise the programme by answering the questions attached.

Please try these questions on your own **without discussion** with colleagues. This will help us know how if there are any gaps in your arithmetical knowledge and will help us to know where to start teaching.

We guarantee that NONE of this information will in ANY WAY influence your performance record either negatively or positively.

Katy Harries, Lecturer: Division of Pharmacology, School of Health Sciences

I agree to answer the questions, on the understanding that the results will be used to help with the design of curriculum relative to the dosing of medicines and will in no way be used as part of my assessment for degree purposes.

I consent to the possible written publication of the overall findings provided that my identity is kept confidential, and that I can in no way be identified via the text.

Signed_____

Student number_____

3. Sample information sheet and consent form for observed teaching interaction

UKZN BIOMEDICAL RESEARCH ETHICS COMMITTEE

APPLICATION FOR ETHICS APPROVAL
For research with human participants (Biomedical)

Information Sheet and Consent to Participate in Research

Date: _____

Dear _____ (name of participant)

My name is Katy Harries from the Division of Pharmaceutical Sciences, UKZN
Email: harriesk@ukzn.ac.za
Phone: 0312604337

You are being invited to consider participating in a study that involves research (**Investigation into drug dosage practices and proportional reasoning in mathematics among medical students**). The aim and purpose of this research is to understand what students need so that we can revise the programme to best support you to be able to use mathematical reasoning to treat patients optimally and it is the title of my PhD project. The research will be conducted at our department at medical school. It will involve the following procedures: answering correctly, while 'thinking aloud', written problems that you have previously calculated incorrectly, with guidance where necessary. We would like to ask permission to make notes and record you, which would later be transcribed and analysed.

The duration of your participation if you choose to enroll and remain in the study is expected to be (between 15 minutes and an hour on one occasion).

The study may involve some inconvenience to you in terms of time. We hope that the study will create the benefit that your mathematical reasoning skills improve and you will find it easier to use these skills appropriately in your work. We guarantee that none of this information will be conveyed to the Faculty and that it will in no way influence your performance record either negatively or positively. Should you choose not to participate, you may still work through these questions with our guidance.

This study has been ethically reviewed and approved by the UKZN Biomedical research Ethics Committee (approval number BE185/09).

In the event of any problems or concerns/questions you may contact the researcher
Katy Harries at
Email: harriesk@ukzn.ac.za
Phone: 0312604337

or the UKZN Biomedical Research Ethics Committee, contact details as follows:

BIOMEDICAL RESEARCH ETHICS ADMINISTRATION

Research Office, Westville Campus

Govan Mbeki Building

Private Bag X 54001
Durban
4000

KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2604769 - Fax: 27 31 2604609
Email: BREC@ukzn.ac.za
Participation in this research is voluntary (and you may withdraw participation at any point), and that if you choose to refuse/withdraw from participation you will be penalized in any.

Every effort will be made to keep your identity and information confidential. Names and student numbers will be kept separate from notes and transcripts which will be given an identification code. Data will be kept locked in our department and electronic information will only be accessible with a password known only to the researcher. The overall findings will be used to provide information to the faculty in order to revise the course if necessary, and will also be written up for publication in the educational literature. You will in know way be identifiable via the text.

CONSENT (Edit as required)

I _____(Name) have been informed about the study entitled **Investigation into drug dosage practices and proportional reasoning in mathematics among medical students** by Katy Harries.

I understand the purpose and procedures of the study:
Answering correctly, while 'thinking aloud', written problems that I have calculated incorrectly, with guidance where necessary, while notes are taken and being recorded.

I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.

I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without affecting any treatment or care that I would usually be entitled to.

I have been informed about any available compensation or medical treatment if injury occurs to me as a result of study-related procedures.

If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher,
Katy Harries at
Email: harriesk@ukzn.ac.za or
Phone: 0312604337 (office hours)

If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers then I may contact:

BIOMEDICAL RESEARCH ETHICS ADMINISTRATION

Research Office, Westville Campus

Govan Mbeki Building

Private Bag X 54001
Durban
4000

KwaZulu-Natal, SOUTH AFRICA

Tel: 27 31 2604769 - Fax: 27 31 2604609

Email: BREC@ukzn.ac.za

Signature of Participant	Date
Signature of Witness	Date

3.1 Paper 1: South African Journal of Anaesthesia and Analgesia

Login or Register to make a submission.

Submission Preparation Checklist

As part of the submission process, authors are required to check off their submission's compliance with all of the following items, and submissions may be returned to authors that do not adhere to these guidelines.

- ✔ This manuscript has currently only been submitted to SAJAA and has not been published previously.
- ✔ This work is original and all third party contributions (images, ideas and results) have been duly attributed to the originator(s).
- ✔ Permission to publish licensed material (tables, figures, graphs) has been obtained and the letter of approval and proof of payment for royalties have been submitted as supplementary files.
- ✔ The submitting/corresponding author is duly authorised to herewith assign copyright to the South African Society of Anaesthesiologists (SASA).
- ✔ All co-authors have made significant contributions to the manuscript to qualify as co-authors.
- ✔ Ethics committee approval has been obtained for original studies and is clearly stated in the methodology as well as provided as a supplementary file.

- ✔ A conflict of interest statement has been included where appropriate.
- ✔ The submission adheres to the instructions to authors in terms of all technical aspects of the manuscript.
- ✔ Plagiarism: The submitting author acknowledges that the Editorial Board reserves the right to use plagiarism detection software on any submitted material.

Author Guidelines

Submitted manuscripts that are not in the correct format and without the required supporting documentation specified in these guidelines will be returned to the author(s) for correction and will delay publication.

AUTHORSHIP

Named authors must consent to publication **by signing a covering letter** which should be submitted as a supplementary file. Authorship should be based on substantial contribution to:

(i) conception, design, analysis and interpretation of data;

(ii) drafting or critical revision for important intellectual content; and

(iii) approval of the version to be published. These conditions must all be met (uniform requirements for manuscripts submitted to biomedical journals; refer to **www.icmje.org**); and

(iv) exact contribution of each author must be stated.

DECLARATION OF CONFLICT OF INTEREST

Authors must declare all sources of support for the research and any association with a product or subject that may constitute a conflict of interest. If there is no conflict of interest to declare please include the following statement: The authors declare no conflict of interest.

FUNDING SOURCE

All sources of funding should be declared. Also define the involvement of study sponsors in the study design, collection, analysis and interpretation of data; the writing of the manuscript; the decision to submit the manuscript for publication. If the study sponsors had no such involvement, this should be stated as follows: No funding source to be declared.

RESEARCH ETHICS COMMITTEE APPROVAL

The submitting author must provide written confirmation of Research Ethics Committee approval for all studies including case reports. The ethics committee as well as the approval number should be included.

STATISTICAL ANALYSIS

Authors are advised to involve medical statisticians at the protocol stage of their research project: to plan sample size, and the selection of appropriate statistical tests for analysis and presentation.

PROTECTION OF PATIENT'S RIGHTS TO PRIVACY

Identifying information should not be published in written descriptions, photographs, and pedigrees unless the information is essential for scientific purposes and the patient (or parent or guardian) gives informed written consent for publication. The patient should be shown the manuscript to be published. Refer to **www.icmje.org**.

ETHNIC CLASSIFICATION

The rationale for analysis based on racio-ethnic-cultural categorisation should be indicated.

CATEGORIES OF SUBMISSIONS

Shorter items are more likely to be accepted for publication, owing to space constraints and reader preferences.

Original articles

Original articles on research relevant to anaesthesia and analgesia should not exceed 3 200 words, no more than 30 references, with up to 6 tables or figures. A structured abstract under the following headings, Background, Methods, Results, and Conclusions is a requirement and should not exceed 300 words.

Clinical Review articles

Review articles relevant to anaesthesia and analgesia should not exceed 2 400 words, with a maximum of 20 references and no more than 6 tables or figures. A summary of 300 words or less is required.

Case reports

Case reports should not exceed 1 800 words with no more than 10 references. Figures are limited to 2 figures and may include images or photographs. The case report should have three headings: Summary (not exceeding 100 words), Case report (with no introduction) and Discussion. Case reports will be published online only. The summary and the URL will appear in the printed version.

Scientific Letters

Scientific Letters should not exceed 2 400 words with a maximum of 10 references. Only one table or illustration is permissible. A structured abstract under the following headings, Background, Methods, Results, and Conclusions, is a requirement and should not exceed 250 words.

Letters to the editor

Letters to the editor should be 800 words or less with only one image or table.

MANUSCRIPT PREPARATION

Refer to articles in recent issues for the presentation of headings and subheadings. If in doubt, refer to 'uniform requirements' - **www.icmje.org**. Manuscripts must be provided in **UK English**.

Qualification, affiliation and contact details

This information must be provided for ALL authors and must be submitted as a supplementary file.

Email addresses of all author must be provided.

ORCID number of **ALL** authors must be provided – if authors do not have ORCID, please register at https://orcid.org/

Abbreviations

All abbreviations should be spelt out when first used and thereafter used consistently, e.g. 'intravenous (IV)' or 'Department of Health (DoH)'.

Scientific measurements

Scientific measurements must be expressed in SI units except blood pressure (mmHg) and haemoglobin (g/dl). Litres is denoted with a lowercase 'l' e.g. 'ml' for millilitres). Units should be preceded by a space (except for %), e.g. '40 kg' and '20 cm' but '50%'. Greater/smaller than signs (> and 40 years of age) should also be preceded by a space e.g. > 20 years. No spaces should precede ± and °, i.e. '35±6' and '19°C'.

Numbers should be written as grouped per thousand-units, i.e. 4 000, 22 160...

Quotes should be placed in single quotation marks: i.e. The respondent stated: '...'
Round **brackets** (parentheses) should be used, as opposed to square brackets, which are reserved for denoting concentrations or insertions in direct quotes.

General formatting

The manuscript must be in Microsoft Word or RTF document format. Text must be 1,5-spaced, in 12-point Times New Roman font, and contain no unnecessary formatting (such as text in boxes, except for Tables). *The manuscript must be free of track changes.*

Disclaimers should follow the Conclusion and it should be in the following order:
Acknowledgements, Declaration conflict of interest, Funding source, Ethics declaration and ORCID.

ILLUSTRATIONS AND TABLES

If tables or illustrations submitted have been published elsewhere, the author(s) should provide consent to republication obtained from the copyright holder.

Tables may be embedded in the manuscript file **and** provided as **'supplementary files'**. They must be numbered in Arabic numerals (1,2,3...) and referred to consecutively in the text (e.g. 'Table 1'). Tables should be constructed carefully and simply for intelligible data representation. Unnecessarily complicated tables are strongly discouraged. Tables must be cell-based (i.e. not constructed with text boxes, tabs or enters) and accompanied by a concise title and column headings. Footnotes must be indicated with consecutive use of the following symbols: * † ‡ § ¶ || then ** †† ## etc.

Figures must be numbered in Arabic numerals and referred to in the text e.g. '(Figure 1)'. Figure legends: Figure 1: 'Title...'. All illustrations/figures/graphs must be of **high resolution/quality**: 300

dpi or more is preferable, but images must not be resized to increase resolution. Unformatted and uncompressed images must be attached as '**supplementary files**' upon submission (not embedded in the accompanying manuscript). TIFF and PNG formats are preferable; JPEG and PDF formats are accepted, but authors must be wary of image compression. Illustrations and graphs prepared in Microsoft PowerPoint or Excel must be accompanied by the original workbook.

REFERENCES

Authors must verify references from the original sources. *Only complete, correctly formatted reference lists will be accepted.* Reference lists may be generated with the use of reference manager software, but the final document must be delinked from the reference database or otherwise generated manually. Citations should be inserted in the text as superscript, e.g. These regulations are endorsed by the World Health Organization,[2] and others.[3,4-6] The superscript reference number should come after the punctuation mark and should not be in brackets.

All references should be listed at the end of the article in numerical order of appearance in the **Vancouver style** (not alphabetical order). Approved abbreviations of journal titles must be used; see the List of Journals in Index Medicus. Names and initials of all authors should be given; if there are more than six authors, the first four names should be given followed by et al. First and last page, volume and issue numbers should be given. **Wherever possible, references must be accompanied by a digital object identifier (DOI) link and PubMed ID (PMID)/PubMed Central ID (PMCID).** Authors are encouraged to use the DOI lookup service offered by **CrossRef**. Crossref DOIs should always be displayed as a full URL link in the form https://doi.org/10.xxxx/xxxxx

Journal references:

1. Jun BC, Song SW, Park CS, Lee DH. The analysis of maxillary sinus aeration according to aging process: volume assessment by 3-dimensional reconstruction by high-resolutional CT scanning. Otolaryngol Head Neck Surg. 2005 Mar;132(3):429-34.
2. Polgreen PM, Diekema DJ, Vandeberg J, Wiblin RT, et al. Risk factors for groin wound infection after femoral artery catheterization: a case-control study. Infect Control Hosp Epidemiol [Internet]. 2006 Jan [cited 2007 Jan 5];27(1):34-7. Available from: http://www.journals.uchicago.edu/ICHE/journal/issues/v27n1/2004069/2004069.web.pdf.

Book references: Jeffcoate N. Principles of Gynaecology. 4th ed. London: Butterworth, 1975:96-101. *Chapter/section in a book:* Weinstein L, Swartz MN. Pathogenic Properties of Invading Microorganisms. In: Sodeman WA jun, Sodeman WA, eds. Pathologic Physiology: Mechanisms of Disease. Philadelphia: WB Saunders, 1974:457-472.

Internet references: World Health Organization. The World Health Report 2002 - Reducing Risks, Promoting Healthy Life. Geneva: World Health Organization, 2002. http://www.who.int/whr/2002 (accessed 16 January 2010).

Other references (e.g. reports) should follow the same format: Author(s). Title. Publisher place: publisher name, year; pages. Cited manuscripts that have been accepted but not yet published can be included as references followed by '(in press)'. Unpublished observations and personal communications in the text must not appear in the reference list. The full name of the source person must be provided for personal communications e.g. '...(Prof. Michael Jones, personal communication)'.

COVERING LETTER

A covering letter to the editor is mandatory and must include statements that the manuscript has not been published previously and is not under review elsewhere. It should state details of any prior publication of the research in abstract form or in Congress proceedings. The letter must declare if any of the authors have a conflict of interest and that the requirements for submission, including ethics approval and patient permission for case reports have been fulfilled. All authors must sign the covering letter.

REVIEW PROCESS

Manuscripts, after vetting by the editorial team, are assigned for peer-review to 2 reviewers, conversant with the particular field of research. The reviewers and the authors are blinded to each other's identity. The turn-around time for review and initial editorial decision notification aims to be within 6 weeks of submission.

PROOFS

A PDF proof of an article may be sent to the corresponding author before publication to resolve remaining queries. At that stage, **only** typographical changes are permitted; the corresponding author is required, having conferred with his/her co-authors, to reply within 2 working days in order for the article to be published in the issue for which it has been scheduled.

CHANGES OF ADDRESS

Please notify the editorial department of any contact detail changes, including email, to facilitate communication.

CHARGES

There is no charge for the publication of manuscripts.

Copyright Notice

By submitting manuscripts to SAJAA, authors of original articles are assigning copyright to the SA Society of Anaesthesiologists. Authors may use their own work after publication without written permission, provided they acknowledge the original source. Individuals and academic institutions may freely copy and distribute articles published in SAJAA for educational and research purposes without obtaining permission.

Privacy Statement

The names and email addresses entered in this journal site will be used exclusively for the stated purposes of this journal and will not be made available for any other purpose or to any other party.

3.2 Paper 2 Pythagoras

Author Guidelines for the journal Pythagoras

Overview

The author guidelines include information about the types of articles received for publication and preparing a manuscript for submission. Other relevant information about the journal's policies and the reviewing process can be found under the about section. The **compulsory cover letter** forms part of a submission and must be submitted together with all the required **forms.** All forms need to be completed in English.

Editorials

Editorials are by invitation only and are intended to provide expert comment on relevant topics within the focus and scope of the journal.

Word limit	800 words
References	10 or less

Book Reviews

Book reviews are brief articles providing insights or opinions on new books within the research field of the journal. Please contact the editor if you would like to suggest a book for review.

Word limit	1000 words

Original Research Articles

An original article provides an overview of innovative research in a particular field within or related to the focus and scope of the journal, presented according to a clear and well-structured format.

Word limit	12000 words (excluding the unstructured abstract and references)
Unstructured abstract	250 words to cover a Background, Objectives, Method, Results and Conclusion
References	60 or less
Tables/Figures	no more than 7 Tables/Figure
Ethical statement	should be included in the manuscript
Compulsory supplementary file	ethical clearance letter/certificate

Review Articles

Inform a broad readership about fields in which there have been recent important advances of immense, fundamental importance, and highlight unresolved questions and future directions. Standard headings are not always appropriate, but the review should have clear sub-headings to provide order to the manuscript. Reviews are typically invited; thus, authors are encouraged to contact the editors prior to submission to express their interest or ideas for reviews of a particular topic.

Word limit	2500-4000 words (excluding the unstructured abstract and references)
Unstructured abstract	250 words to cover a Background, Objectives, Method, Results and Conclusion

References	40 or less
Tables/Figures	no more than 4 Tables/Figure
Ethical statement	should be included in the manuscript

Cover Letter

The format of the compulsory cover letter forms part of your submission. Kindly download and complete, in English, the provided **cover letter**.

Anyone that has made a significant contribution to the research and the paper must be listed as an author in your cover letter. Contributions that fall short of meeting the criteria as stipulated in our policy should rather be mentioned in the 'Acknowledgements' section of the manuscript.
Read our **authorship** guidelines and **author contribution** statement policies.

Original Research Article full structure

Title: The article's full title should contain a maximum of 95 characters (including spaces).

Abstract: The abstract, written in English, should be no longer than 250 words and must be written in the past tense. The abstract should give a succinct account of the objectives, methods, results and significance of the matter. The unstructured abstract for an Original Research article should consist of five paragraphs unlabelled Background, Objectives, Method, Results and Conclusion.

- Background: *Why do we care about the problem?* State the context and purpose of the study. (What practical, scientific or theoretical gap is your research filling?)
- Objectives: *What problem are you trying to solve*? What is the scope of your work (e.g. is it a generalised approach or for a specific situation)? Be careful not to use too much jargon.
- Method: *How did you go about solving or making progress on the problem*? State how the study was performed and which statistical tests were used. (What did you actually do to get the results?) Clearly express the basic design of the study; name or briefly describe the basic methodology used without going into excessive detail. Be sure to indicate the key techniques used.
- Results: *What is the answer*? Present the main findings (that is, as a result of completing the procedure or study, state what you have learnt, invented or created). Identify trends, relative change or differences on answers to questions.
- Conclusion: *What are the implications of your answer*? Briefly summarise any potential implications. (What are the larger implications of your findings, especially for the problem or gap identified in your motivation?)

Do not cite references and do not use abbreviations excessively in the abstract.

Introduction: The introduction must contain your argument for the social and scientific value of the study, as well as the aim and objectives:

- Social value: The first part of the introduction should make a clear and logical argument for the importance or relevance of the study. Your argument should be supported by use of evidence from the literature.
- Scientific value: The second part of the introduction should make a clear and logical argument for the originality of the study. This should include a summary of what is already known about the research question or specific topic, and should clarify the knowledge gap that this study will address. Your argument should be supported by use of evidence from the literature.
- Conceptual framework: In some research articles it will also be important to describe the underlying theoretical basis for the research and how these theories are linked together in a conceptual framework. The theoretical evidence used to construct the conceptual framework should be referenced from the literature.
- Aim and objectives: The introduction should conclude with a clear summary of the aim and objectives of this study.

Research methods and design: This must address the following:

- Study design: An outline of the type of study design.
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Page 3

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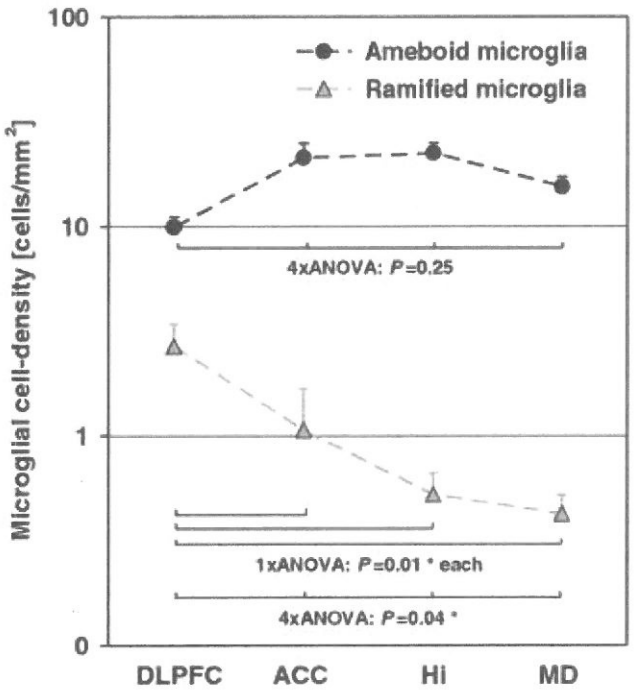

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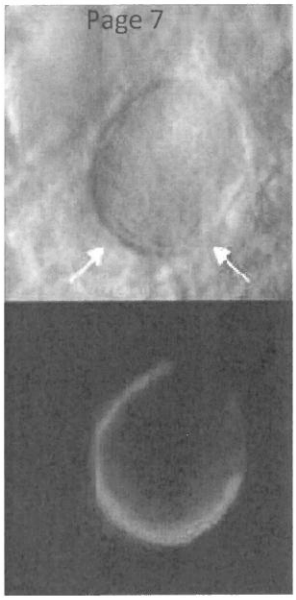

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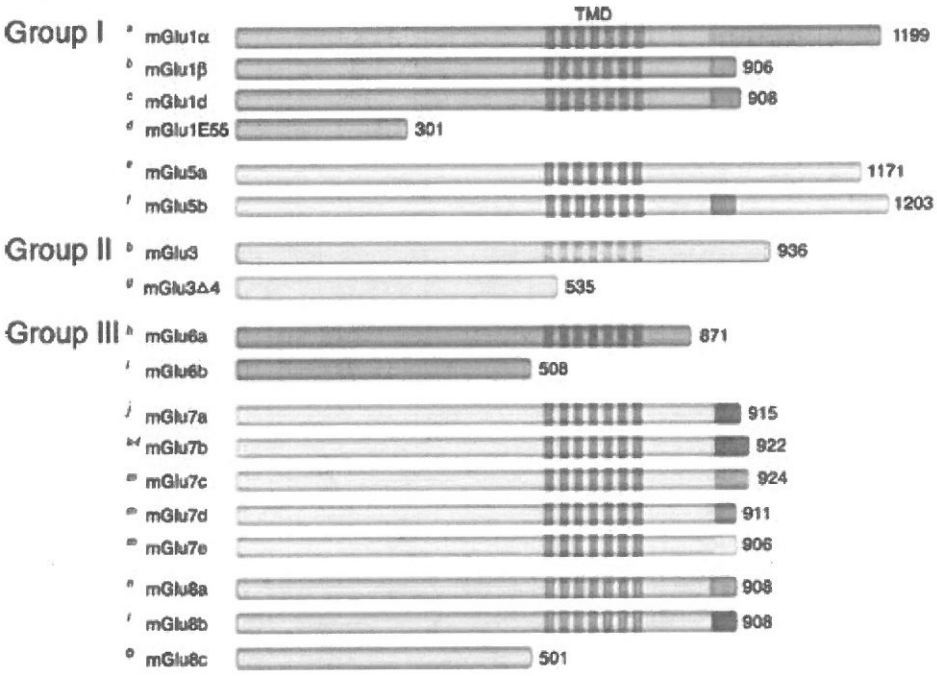

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- Background: Why is the topic important to us? State the context of the review

- Aim: What is the purpose of your review ? Describe the aim or purpose of your review.

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- Results: What are the findings? What are the main findings of your literature review.

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Implications and recommendations: Discuss the findings of your review in terms of the implications for policy makers and clinicians or recommendations for future research.

Conclusion: This should clearly state the main conclusions of the review in terms of addressing the original aim and objectives.

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Dosage calculations

6. Tuition sample slides

6.1 Cycle I sample slides: explaining concentration formatted as a percentage or ratio

Involving concentrations expressed as a percentage

- You plan to suture an 80kg patient. Given the maximum safe dose of lignocaine is 3mg/kg, what is the maximum safe volume, in mL, of 2% lignocaine solution that can be given?

Patient=80kg dose = 3mg/kg therefore 240mg needed

2% = 2g in 100mL

= 2000mg in 100mL

= 200mg in 10mL

=20mg in 1mL

Therefore 240mg in **12mL**

Involving concentrations expressed as a ratio

- How many micrograms (mcg) of adrenaline are there in a 20mL ampoule of 0.5% bupivacaine with adrenaline 1:200 000 solution?

20mL amp

1:200 000 solution

=1g in 200 000mL

=1000mg in 200 000 mL

1mg in 200mL

=1000mcg in 200mL

=**100mcg** in 20mL

Involving concentrations expressed as a mass per unit volume

- You plan to sedate a 25kg child with midazolam. A vial of midazolam has 15mg in 3mL. The intravenous sedation dose of midazolam for children is 0.1mg/kg. How many mL do you need to draw up?

patient = 25kg dose 0.1mg/kg so 2,5mg needed

15mg in 3mL

therefore 5mg in 1mL

and 2.5mg in **0.5mL**

Drip rate calculations

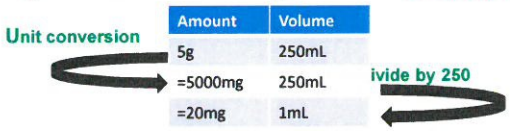
- If 0.6mL (containing 45mg to treat a 3kg neonate) vancomycin solution is added to 50mL of 0.9% sodium chloride, then an appropriate infusion rate to administer this over 60 minutes, using a 60 drop per ml giving set, would be___ drops per minute

$$\text{no of drops/ min} = \frac{\text{drop factor x vol}}{\text{time}}$$

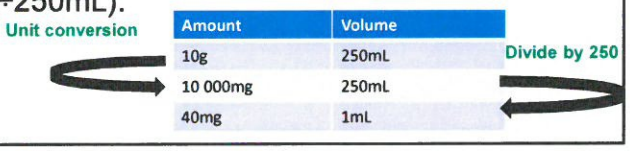
$$\frac{60 \text{ drops/mL x 50mL (or 50.6mL)}}{60\text{min}} = \textbf{50 drops/min}$$

Concentration

Think of a cup of tea with one spoonful of sugar and another with two spoonfuls of sugar. The second cup is sweeter because the **concentration** of sugar is greater.
The first cup has about 5g (one teaspoonful) sugar dissolved in 250mL (one cup) of hot water so the concentration is 5g in 250mL, or 5g/250mL = 5000mg/250mL =20mg/mL (5000mg÷250mL) .



The second cup has 10g sugar dissolved in 250mL hot water so the concentration is 10g in 250mL = 10 000mg in 250mL = 40mg/mL (10000mg÷250mL).



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Concentration

The concentration of medicine in solution is the amount of active ingredient powder dissolved in the amount of liquid (usually water or saline) Concentration=$\frac{\text{mass}}{\text{volume}}$
When you are thinking about concentration you are thinking about
An amount of medicine
Dissolved in a volume of liquid
So you are thinking about two quantities: amount and volume

Amount	Volume

13

Concentration continued

Imagine a child making herself a cup of tea in a big cup

Now she pours it into a teapot and pours the tea out into two dolls' cups

The doll's cups are just as sweet (have same concentration of sugar) as the big cup did

14

Concentration continued

Imagine you weighed out 1g of powdered medicine (called **'active ingredient'**)

and added 100 mL water (the same amount you'd find in a small bottle of cough mixture),

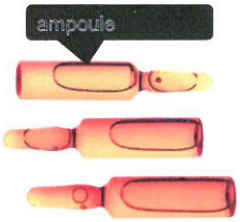
Every spoonful of cough mixture would taste as strong as the cough mixture in the bottle (i.e. they have the same concentration…)

15

Concentration continued

Now imagine you weighed out 1g of powdered medicine (called **'active ingredient'**)

and added 100 mL water



then you shook this and poured into a hundred 1mL ampoules...

16

Concentration continued

...The solution in the bottle and the 1mL amps would all have the same concentration

(just like the spoonfuls of cough mixture or the small cups of tea have the same taste as the cough mixture or tea in the original container)

This is because the relationship between the powder and the liquid stays the same just like the dolls cups are as sweet as the big cup

17

Concentration continued

- You could say you had made a solution of 1g in 100mL

  You could also call this:

  a 1:100 solution (read as 'one in a hundred') or

  a 1% solution or

  10mg/mL because every millilitre of water is **carrying** 10mg of powder dissolved in it

(We even call the liquid the powder is dissolved in a **vehicle)**

18

DOSING DRUGS 1
using analgesics as examples

1

Dosing aspirin tablets

Ex SAMF, aspirin monograph: heading 'adult dose':

Pain or fever: 300-900mg 4-6 hourly as needed; maximum 4g daily

Ex SAMF, aspirin monograph, heading 'preparations include':

Aspirin [N02BA01]

Disprin® Reckitt Benckiser

Dispersible tablets, 300mg

So for pain and fever 1-3 tablets can be prescribed

Maximum 4g: 300mg x 10 = 3000mg = 3g

300mg x 3 = 900mg = 0.9g

Therefore 10 + 3 tabs = 3900mg = 3.9g ≈ 4g

Therefore don't take more than 13 tablets in 24 hours

2

Dosing morphine injection

Ex SAMF, morphine monograph: heading 'adult dose':

IM or SC, 5-20mg (usually 10mg initially, based on an adult weighing 70kg): repeated 4-6 hourly as required

Ex SAMF, morphine monograph, heading 'preparations include':

Morphine [N02AA01] S7

Morphine Sulphate-Fresenius® Bodene

inject, 10mg/mL, 15mg/mL

So if the 10mg/mL amp is chosen contains 10mg in 1mL

So divide by 2: contains 5mg in half a mL (0.5mL)

And multiply by 2: contains 20mg in 2mL

So you could give 0.5-2mL. If you want to give the usual dose you could give 1mL - the entire contents of the 10mg amp

3

Dosing paracetamol syrup

Ex SAMF, paracetamol monograph: heading 'paediatric dose':

Analgesia/pyrexia (acute or severe symptoms): Oral or rectal,over 1 month old, 20mg/kg/dose 6 hourly; maximum 90mg/kg/24 hours.

Ex SAMF, paracetamol monograph, heading 'preparations include':

Paracetamol [INN][N02BE01]

Panado® Al Self Med

***tablets*, 500mg, *capsules*, 500mg, *effervescent tablets*, 500mg**

***children's chew tabs*, 120mg, *infant drops*, 60mg/0.6mL**

***paediatric syrup* (sugar/alcohol free), 120mg/5mL, *syrup* 120mg/5mL**

4

Dosing paracetamol syrup

'paediatric dose': *Analgesia/pyrexia (acute or severe symptoms):* Oral or rectal,over 1 month old, 20mg/kg/dose 6 hourly; maximum 90mg/kg/24 hours.

'preparations include': ***paediatric syrup*(sugar/alcohol free),120mg/5mL,*syrup* 120mg /5mL**

Choose the paediatric syrup: So we have 120mg in a 5mL medicine measureful

Let's work out the dose for a 12kg child:

So we need 20mg/kg/dose

20mg/kg x 12kg for 1 dose = 240mg

There is 120mg in 5mL

And 240mg in ?mL

120mg in 5 mL

so 1mg in 5/120mL

And 240mg

in 5/120 x 240mL

=10mL (2 medicine spo

need / got

Amount	Volume
240mg	?
120mg	5mL
1mg	$\frac{5mL}{120}$
240mg	$\frac{5mL}{120}$ x 240
240mg	10mL

First step to 1 by dividing by 120

Then step to 240 by multiplying by 240

5

Dosing paracetamol syrup

'paediatric dose':*Analgesia/pyrexia (acute or severe symptoms):* Oral or rectal,over 1 month old, 20mg/kg/dose 6 hourly; maximum 90mg/kg/24 hours.

'preparations include': ***paediatric syrup*(sugar/alcohol free),120mg/5mL,*syrup* 120mg /5mL**

paediatric syrup chosen: So 120mg in a 5mL measureful

The dose for a 12kg child is 20mg/kg x 12kg (1 dose) = 240mg

Maximum 90mg/kg/24 hours

= 90mg x 12kg in 1 day

=1080mg in 1day

There is 120mg in 5 mL

so 1mg in 5/120mL

and 1080mg in 5/120x 108

= 45 mL

(or 9 measuresful)

need / got

Amount	Volume
1080 mg	?
120 mg	5 mL
1mg	$\frac{5}{120}$ mL
1080mg	$\frac{5}{120}$ x 1080 mL
1080mg	45mL

First step to 1 by dividing by 120

Then step to 1080 by multiplying by 1080

6

Standard treatment guidelines

ACUTE PAIN CONTROL

Drug treatment

Acute, mild pain

» Non-opioid treatment

Non-inflammatory or post trauma

Children:

- **Paracetamol**, oral, 15 mg/kg/dose 4–6 hourly when required to a maximum of 4 doses per 24 hours
  - In children under 6 months calculate dose by weight

Weight kg	Dose mg	Use one of the following: Syrup 120 mg/5mL	Tablet 500 mg	Age months/years
≥3.5–5 kg	48 mg	2 mL	–	≥ 1–3 months
≥ 5–7 kg	60 mg	2.5 mL	–	≥ 3–6 months
≥ 7–9 kg	96 mg	4 mL	–	≥ 6–12 months
≥ 9–14 kg	120 mg	5 mL	–	≥ 12 months–3 years
≥ 14–17.5 kg	180 mg	7.5 mL	–	≥ 3–5 years
≥ 17.5–35 kg	240 mg	10 mL	½ tablet	≥ 5–11 years
≥ 35–55 kg	500 mg	–	1 tablet	≥ 11–15 years
≥55kg and above	Upto 1000mg	–	Upto2tablets	≥ 15 years and adults

7

Paracetamol dose for EDL guidelines

Calculated by weight:

15mg/kg/dose for a 12 kg child

= 15 x 12=180mg

120mg in 5mL

180 mg in ?mL

1mg in 5mL/120

180mg in 5/120 x 180

=7.5 mL

(7.5/5mL = 1 ½

so one and a half spoonfuls)

	Amount	Volume
want	180mg	?
got	120mg	5mL
divide by 120 to get 1	1mg	$\frac{5mL}{120}$
multiply by 180 to get 180	180mg	$\frac{5mL}{120}$ x180
	180	7.5mL

Calculated by weight band:

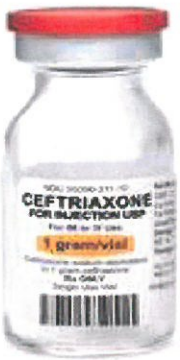
One medicine measureful per dose because also includes the 9kg children

8

PREPARING AND ADMINISTERING AN INJECTABLE DRUG

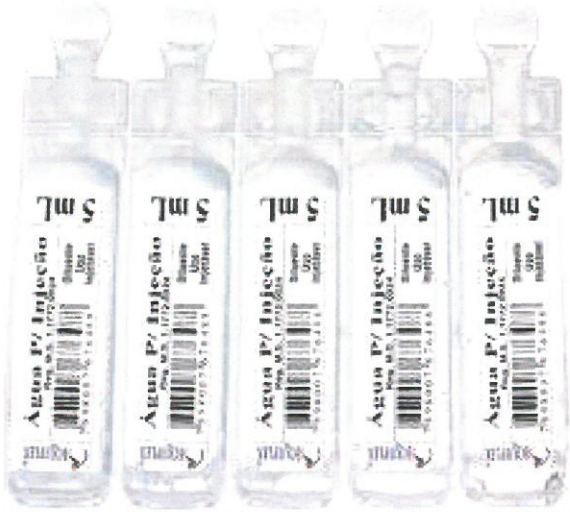
1

A vial....and ampoules (or amps)



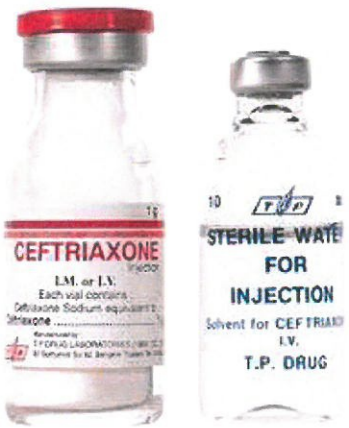
2

Plastic amps of water for injection or saline



3

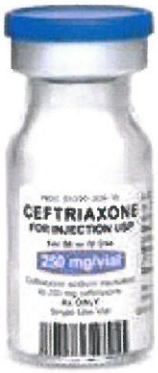
Some drugs need to be reconstituted



This means they have been dehydrated and need to be restored to their former condition by adding water (like stock powder or cup-a-soup!)

4

Quick intro to ceftriaxone



It is a drug used to treat an infection

It kills the microorganism (a kind of bacteria) causing the infection

It is called an antimicrobial (commonly referred to as an antibiotic-not technically the right name but ok for us for now

5

A dosing example from the EDL- where a drug needs to be reconstituted

2.8.1 Diarrhoea, acute in children

Description

A sudden onset of change in consistency and frequency of stools with or without vomiting in children.
It is commonly caused by a virus but may be caused by bacteria or parasites.
The cause of these conditions cannot be diagnosed without laboratory investigation.
It may be an epidemic if many patients are infected at the same time.

Special risk situations

Diarrhoea in infants less than 2 weeks, malnourished babies, and babies with other danger signs such as:

- convulsions
- altered level of consciousness
- persistent vomiting
- respiratory distress
- persistent diarrhoea
- hypothermia
- surgical abdomen

Refer these babies urgently for treatment. Before referral, administer:

- Ceftriaxone, IM, 50–80 mg/kg/dose immediately as a single dose

6

- Ceftriaxone, IM, 50–80 mg/kg/dose immediately as a single dose

Weight kg	Dose mg	Use one of the following injections mixed with water for injection (WFI):			Age Months/ years
		250 mg WFI 2 mL	500 mg WFI 2 mL	1 000 mg WFI 3.5 mL	
≥ 2–2.5 kg	125 mg	1 mL	0.5 mL	–	
≥ 2.5–3.5 kg	200 mg	1.6 mL	0.8 mL	–	Birth–1 month
≥ 3.5–5.5 kg	250 mg	2 mL	–	–	≥ 1–3 months
≥ 5–7 kg	375 mg	3 mL	–	–	≥ 3–6 months
≥ 7–9 kg	500 mg	4 mL	2 mL	–	≥ 6–12 months
≥ 9–11 kg	625 mg	5 mL	2.5 mL	–	≥ 12–18 months
≥ 11–14 kg	750 mg	6 mL	3 mL	–	≥ 18 months–3 years
≥ 14–17.5 kg	1 000 mg	–	4 mL	3.5 mL	≥ 3–5 years
≥ 17.5 kg and above	1 000 mg	–	4 mL	3.5 mL	≥ 5 years and adults

7

If you wanted to give a 2.5kg baby 50mg/kg...

- Ceftriaxone, IM, 50–80 mg/kg/dose immediately as a single dose

Weight kg	Dose mg	Use one of the following injections mixed with water for injection (WFI):			Age Months/ years
		250 mg WFI 2 mL	500 mg WFI 2 mL	1 000 mg WFI 3.5 mL	
≥ 2–2.5 kg	125 mg	1 mL	0.5 mL	–	

50mg/kg x 2.5kg = 125mg

This is the amount of medicine (in powder form) you want to dissolve and get into your patient's body to fight the bugs there

There are 3 different strengths of vial available in South Africa : one containing 250mg powder, one containing 500mg powder and one containing 1G (gram) of powder.

If you have the 250mg vial you should mix it with 2mL Water For Injection (WFI)

Now you have a drug concentration expressed as a unit of mass/ unit of volume e.g. 250mg/2mL

8

Working out a dose from a concentration expressed as a unit of mass /unit of volume

- So you have 250mg in 2mL =125mg in 1mL or 125mg/mL. You need to give 1mL of the solution and discard the rest.
- If you have the 500mg vial you should mix it with 2mL WFI to give you

  500mg in 2mL= 250mg in 1mL

  You want 125mg in ? mL cross-multiply or use the stepping stone of 1 i.e. 1mg in 1/250mL and 125mg in 1/250mL x 125 = 125/250 = ½ mL or 0.5mL

9

Now try 50mg/kg for a 5kg child and 60mg/kg for a 3.4kg child..

- Ceftriaxone, IM, 50–80 mg/kg/dose immediately as a single dose

Weight kg	Dose mg	Use one of the following injections mixed with water for injection (WFI):			Age Months/ years
		250 mg WFI 2 mL	500 mg WFI 2 mL	1 000 mg WFI 3.5 mL	
≥ 2–2.5 kg	125 mg	1 mL	0.5 mL	–	
≥ 2.5–3.5 kg	200 mg	1.6 mL	0.8 mL	–	Birth–1 month
≥ 3.5–5.5 kg	250 mg	2 mL	–	–	≥ 1–3 months

- 50mg/kg x 5kg = 250mg so get a 250mg vial, add 2mL WFI and inject all 2mL IM (intramuscularly) to get 250mg into patient

- 60mg/kg x 3.4kg = 204mg either work out exactly have 250mg in 2mL =125mg/mL need 204 mf in ? mL works out to 1.63 mL or use table: child is 3.4kg so give a dose of 200mg. Take 250mg vial, add 2mL to give 125mg/mL. There is 1mg in 1/125mL and 200mg in 1/125 x 200 = 1.6mL

  📖 Now work out if you used a 500mg vial

10

Sometimes you need to work out a dose for a drug measured in international units (IU)

- This is a unit used to measure the activity (or effect) of some medicines e.g. penicillin and insulin where preparations differ so that 1mg of one preparation of the medicine has a different effect to 1mg of another preparation of the same medicine
- For each of these medicines there is an international agreement specifying the biological effect expected with a dose of 1 IU.

  e.g. 1 IU represents 45.5mcg of a standard preparation of insulin or 0.6mcg of a standard preparation of penicillin
- For many substances there is no definite conversion between IU and mass units (eg. mg). This is because preparations of those substances vary in activity so the effect of 1mg of one preparation is different from 1mg of another.

11

Quick intro to benzathine penicillin

- It is an antibiotic that was developed from the first kind of penicillin discovered: benzylpenicillin
- It differs from benzylpenicillin because it is long-acting and only needs to be given to the patient weekly or monthly
- It slowly moves from the muscle to the bloodstream: we call this kind of medicine a depot preparation
- It must ONLY be given intramuscularly (IM)

12

A dosing example from the EDL- where a drug measured in IU is needed

4.9 Rheumatic fever, acute
I01.9
Note: notifiable condition.

Description

A condition in which the body develops antibodies against its own tissues following a streptococcal throat infection. Effective treatment of streptococcal pharyngitis can markedly reduce the occurrence of this disease. Commonly occurs in children between 3 and 15 years of age.

Clinical signs and symptoms include:
- arthralgia or arthritis that may shift from one joint to another
- carditis including cardiac failure
- heart murmurs
- subcutaneous nodules
- erythema marginatum
- chorea (involuntary movements of limbs or face)
- other complaints indicating a systemic illness e.g. fever

13

Preparing benzathine penicillin

Drug treatment

Eradication of streptococci in throat

- Benzathine benzylpenicillin, IM, single dose
  - Children under 30 kg: 600 000 IU
  - Children over 30 kg and adults: 1.2 MU

Above is part of the drug treatment for rheumatic fever from the EDL Below is information found on a package insert for one preparation of benzathine penicillin:

To reconstitute a single vial (900mg) of Pan Benzathine Penicillin, 4ml of water for injection must be added to the powder in the vial which provides a final volume of approximately 4.6ml

So give all 4.6mL to children over 30kg and adults (1.2mU) and half the dose (1.2 mU/2 = 600 000 IU (2.3 mL) to children under 30kg

14

Sometimes a drug concentration is given as a ratio ..

A dosing example from the EDL

- where a drug concentration is given as a ratio

21.4.1 Cardiac arrest adults

- Below is part of the treatment

Immediate emergency drug treatment
Adrenaline is the mainstay of treatment and should be given immediately, IV or endobronchial, when there is no response to initial resuscitation or defibrillation.

- Adrenaline, 1:1 000, 1 mL, IV immediately as a single dose

What amount of adrenaline are you giving in mg?

15

Ratio question continued

1:1000 adrenaline is the same as saying 1g adrenaline in 1000mL solution

1g in 1000mL

So 1000mg in 1000mL

So 1mg in 1mL

Need to give 1mL

= 1mg

16

Sometimes a drug concentration is given as a percentage ..

- A dosing example from the EDL
- where a drug concentration is given as a percentage

- Below is part of the treatment :

21.2.2 Insect stings and spider bites

What amount of lignocaine are you giving?

Very painful scorpion stings
- Lignocaine 2%, 2 mL injected around the bite as a local anaesthetic

17

Percentage Question Continued

- 2% lignocaine is the same as saying 2g lignocaine dissolved in 100mL solution

2g in 100mL = 2000mg in 100mL = 20mg in 1mL

? In 2mL

20mg x 2 =40mg

18

An example which end up with an IV Infusion..

You diagnose bacterial meningitis in a sick 11kg 1-year old child at your clinic. You administer ceftriaxone (the dose is 50-80mg/kg IM and you decide to give 750mg) and arrange transfer to the nearest hospital. There she is given ceftriaxone 50mg/kg/dose 12 hourly by IV infusion

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Excerpts from Primary Health Care Standard Treatment Guidelines (STGs)

Drug treatment

If bacterial meningitis is strongly suspected, or if any danger signs are present (depressed level of consciousness, purpura), initiate drug treatment before transfer. The threshold for giving antibiotics before referral to young children, especially neonates, should be extremely low.

- Ceftriaxone, IM, 50–80 mg/kg/dose immediately as a single dose before referral.

And from the Paediatric Hospital STGs

8.9 MENINGITIS, ACUTE BACTERIAL

G00

* Notifiable condition. (*N. meningitidis* and *H. influenzae*)

DRUG TREATMENT

Antibiotic therapy

Duration of treatment:

N. meningitidis	5 days
S. pneumoniae	12 days
H. influenzae	7 days

In complicated cases, a longer duration of therapy may be required.
Reassess antimicrobial therapy when blood and CSF culture and sensitivity results become available, or when improvement is not evident within 72–96 hours.

- cefotaxime, IV, 25–50 mg/kg/dose, 6–8 hourly
  OR
  ceftriaxone, IV, 50 mg/kg/dose 12 hourly

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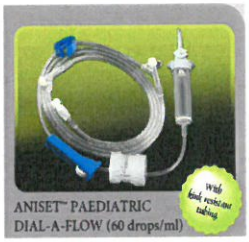
A closer look at the IV infusion

An administration set (or 'giving set') is attached to the minibag and connected to an intravenous catheter which goes into the patient's vein

This is an adult giving set with a drop size of 15 drops/mL. You need 15 of these drops to make 1millilitre



This is a paediatric giving set with a drop size of 60 drops/mL These drops are quarter of the size of the drops in the adult giving set adult because you need 60 of them to make 1mL

This is a picture of intravenous catheters

21

Working out the volume of medicine required to be injected into the minibag

50mg/kg/dose of ceftriaxone needed for an 11kg child in hospital

50mg/kg/dose x 11 kg = 550mg/dose

Use a 1g vial (as the dose needed is more than 500mg).

In the package insert for ceftriaxone the information for reconstituting ceftriaxone for intravenous infusion is as follows

Add 10mL WFI to give 1g in 10mL & shake well

Amount	Volume
1000mg	10mL
Divide by 1000	
1mg	10/1000mL
Multiply by 550	
550mg	10/1000 x 550
	5.5mL

Remove 5,5mL from the vial and inject this into the minibag

22

Tackling IV infusion flow rate

Flow rate is the speed at which a volume of liquid moves from one place to the next = volume of liquid moved / time taken to move the liquid

You need to move 50mL (well 55.5mL if you want to be really exact) from the minibag to the patient's vein. The chamber on the administration set breaks the mLs into drops (either 15 drops for every mL for adults or 60 really tiny drops for every mL for children). You want to set the the rate so that it's not too fast (> 1 drop/s is too fast) and not too slow.

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Tackling IV infusion flow rate continued

- Let's say we use the 60drops/mL administration set (the drop factor of the admin set is 60drops/mL) this means that as we have a roughly 50mL minibag we have 50mL x 60drops/mL =3000drops to move. We could set the rate at 3000drops/60 min = 50 drops/minute

Because we actually had 55.5mL not 50 mL we have 55.5mL x 60 drops/mL = 3330drops to move

$$\frac{3330 \text{ drops}}{50 \text{drops/minute}} = 66.6 \text{minutes}$$

At the rate of 50 drops/minute it will take 66.6 minutes to finish giving the medicine which is ok as this is close to 60minutes and the drip won't be taken down until it is finished

$$\text{flow rate (drops/min)} = \frac{\text{drop factor (drops/mL)} \times \text{volume}}{\text{time}}$$

- If we tried to administer all the medicine in 30minutes the rate would be 3000drops/30min =100drops/minute

This is a bit too fast because 100 drops in a minute is more than 1 drop /second, so better to give this over 60 minutes

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6.5 Cycle II and III digoxin example
Page I

The following is an excerpt from the profile of the medicine **digoxin** in the SAMF 12th Edition:

Paediatric dose: **Guided by therapeutic drug monitoring.** Maintenance: oral, 0.01mg/kg/day in 1-2 divided doses, adjusted according to serum levels.
Digitalising (rarely required): oral, 0.015mg/kg in 3 divided doses over 24 hours and check whether therapeutic serum levels have been obtained.

Preparations include:
Lanoxin® Aspen Pharmacare
tablets, 0.25mg, (**PG** *paed/geriatric)* 0.0625mg,
elixir (paediatric/geriatric), 0.05mg/mL
inject, 0.25mg/mL (2mL ampoule)
Purgoxin® Aspen Pharmacare *tablets* 0.25mg

Digitalising dose also called Loading dose= the starting dose (for first dose or first day), then maintenance dose (for doses after that

If a 15kg boy is prescribed an appropriate maintenance dose of digoxin twice daily, what volume of digoxin paediatric elixir would be required for one dose?

A 1mL
B. 1.5mL
C. 3mL
D. 0. 075mL

Page II

If a 15kg boy is prescribed an appropriate **maintenance** dose of digoxin twice daily, what volume of digoxin paediatric elixir would be required for one dose?

0.01mg/kg/day x 15kg = 0.15mg/day divided by 2 (twice daily) = 0.075mg/dose.

Elixir contains 0.05mg/mL

Amount (mass)	Volume
0.05mg	1mL
Divide by 0.05 to step to 1	Do the same (divide by 0.05)
1mg	1 mg/0.05
Multiply by 0.075	1mg/0.05 x 0.075 = 1.5mL

so you need 1.5mL of this to get dose of 0.075mg

If a 15kg boy is prescribed an appropriate maintenance dose of digoxin twice daily, what volume of digoxin paediatric elixir would be required for one dose? B

A 1mL
B. 1.5mL
C. 3mL
D. 0. 075mL

0.01mg/kg/day x 15kg = 0.15mg/day = 0.075mg/dose. Elixir contains 0.05mg/mL so need 1.5mL of this to get dose of 0.075mg

Understanding risk in drug treatment

Remember the questions in the first lesson this term…

Imagine you just discovered that you have a risk factor for cardiovascular disease (e.g. High LDL cholesterol). A drug that will reduce this risk factor is available, and it has a low incidence of side effects. Consider the 3 following scenarios.

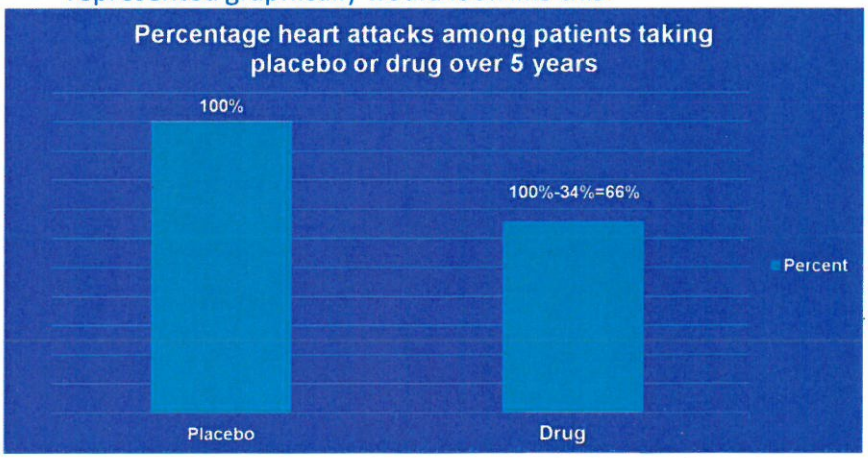
Would you be willing to take this drug daily for the next 5 years if significant results from randomised placebo controlled trials showed that:

1. patients taking this drug for 5 years have 34% fewer heart attacks than patients taking placebo; **or**
2. 2.7% of the patients taking this drug for 5 years had a heart attack, comparing to 4.1% taking a placebo, a difference of 1.4%; **or**
3. if 71 patients took this drug for five years the drug would prevent one from having a heart attack. There is no way of knowing in advance which person that might be.

1

1. patients taking this drug for 5 years have 34% fewer heart attacks than patients taking placebo

To help you make this decision it might help you to think about this risk in terms of a graph-this information represented graphically would look like this:



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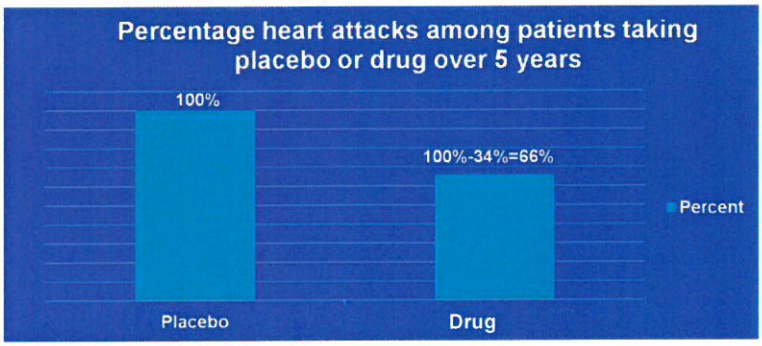
1. patients taking this drug for 5 years have 34% fewer heart attacks than patients taking placebo

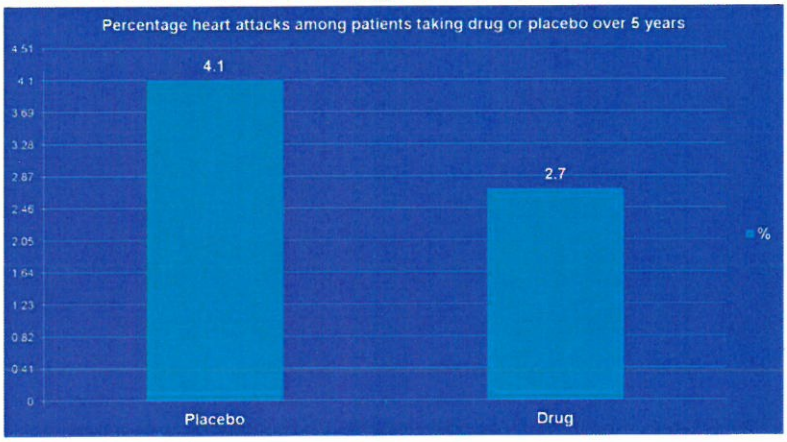


We can say the **relative risk** for this drug is 66% (or the drug tower is about 2/3 as big as the placebo tower) and the **relative risk reduction is 34%** .(this is the part above the blue tower for the drug that would have been blue if the drug had not been given) or that the drug group experience about a third less heart attacks than the patients taking the placebo.

3

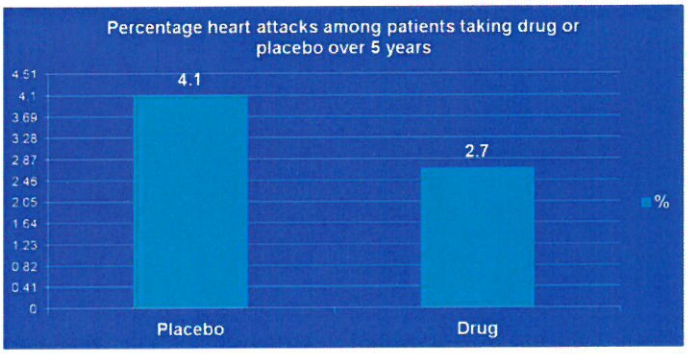
2. 2.7% of the patients taking this drug for 5 years had a heart attack, comparing to 4.1% taking a placebo, a difference of 1.4%

This information represented graphically would look like this:



4

2. 2.7% of the patients taking this drug for 5 years had a heart attack, comparing to 4.1% taking a placebo, a difference of 1.4%



You might notice this graph looks like the graph in Q1. In fact it is the same. 2.7/4.1X100 = 66% so the heart attack rate in the drug group is 66% of the heart attack rate in the placebo group. We can say the relative risk for this drug is 66%. The relative risk reduction is 4.1-2.7/4.1 x100 =1.4/4.1 x 100 = 34%. The Absolute risk for patients in the drug group is 2.7% and in the placebo group 4.1%, so the Absolute risk reduction is 4.1%-2.7% = 1.4%

5

if 71 patients took this drug for five years the drug would prevent one from having a heart attack. There is no way of knowing in advance which person that might be

Every time we treat 71 people, 1 person is saved.

71 people treated = 1 person saved

When we treat 1 person:

(divide by 71) 71/71=1 person treated = 1/71 people saved

So when we treat 100 people

(X100) 71/71 x 100 = 100 people treated =1/71 x 100 1.4%!

Do you recognise 1.4%? it's amount of people saved for every 100 people treated in #2 above! (or the absolute risk reduction)

6

3. if 71 patients took this drug for five years the drug would prevent one from having a heart attack. There is no way of knowing in advance which person that might be

If you take the absolute risk reduction in #2 above and work out the **Number needed to treat** from there you would have 1.4% = 1.4 people saved for every 100 treated

(X10) = 14 people saved for every 1000 treated

(÷ 14) = 1 person saved for every 1000/14= 71 treated

So the 3 scenarios is in fact information that comes from the same study! Here it is...

7

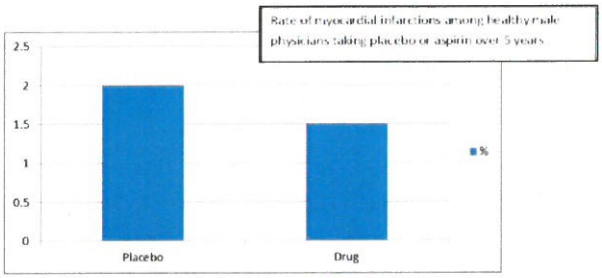
So the 3 scenarios is in fact information that comes from the same study! Here it is...

Clinical trial	Number of patients		Number of events		Event incidence %		RR	RRR	ARR	NNT	Trial duration
	Placebo	Drug	Placebo	Drug	Placebo	Drug					
Gemfibrosil in male patients with high cholesterol (total coronary events)	2030	2051	84	56	4.1	2.7	0.66	34	1.4	71	5 years

8

Now for the second tutorial

The following information has been provided from a trial involving healthy male physicians taking a drug for 5 years to prevent heart attack.
Use the information provided in the graph to estimate answers to the questions below.



Physicians taking the drug for 5 years have more/fewer (circle the most appropriate word) myocardial infarctions than physicians taking the placebo. I would describe this difference in detail as: physicians taking the drug get a quarter less heart attacks/25% less heart attacks

9

Relative risk

Physicians taking the drug get a quarter less heart attacks/25% less heart attacks

Relative risk (RR) = Event rate (drug)/Event rate (Placebo) =1.5%/2% = ¾ or 75%

Relative risk reduction (RRR) = (1-relative risk) x 100 = (1-3/4)x100 =25%

10

Absolute risk

1.5 % of the physicians taking this drug for 5 years had a myocardial infarction, compared to 2 % of the placebo, a difference of 0.5%

% Absolute risk reduction (ARR) = % Event rate (Placebo)- % Event rate (Drug)

= 2%-1.5%=0.5%

11

Number Needed to Treat

If 200 physicians took this drug for 5 years the drug would prevent one physician from having a myocardial infarction. There is no way of knowing in advance who that person might be

d) Number needed to treat (NNT) = 100/% absolute reduction

100/0.5 = 200 (makes sense as 0.5% = 0.5 people (half a person (!) out of 100 people, so x2 to

get 1 person out of every 200 people)

12

7. Tutorial samples

7.1 Cycle I dosage calculation tutorial

1. Lignocaine is available in 5mL ampoules of 2%. How much lignocaine, in milligrams (mg), is in the amp?
   2% = 2g in 100 mL
   = 2000mg in 100mL (divide by 20)
   = 100mg in 5 mL
   So 100mg (in 5 mL amp)

2. You plan to suture a 60kg patient. Given the maximum safe dose of lignocaine is 3mg/ kg, what is the maximum safe volume, in mL, of 10% lignocaine solution that can be given?
   3mg/kg x 60 kg = 180 mg
   10% = 10 g in 100 mL
   = 10 000 mg in 100 mL
   So 1 mg in 100/10 000
   And 180 mg in 100/10 000 x 180
   =1,8 mL

3. A 4mL ampoule containing 0.5% bupivacaine contains how many milligrams per milliliter (mg/mL) of bupivacaine?
   0.5% = 0.5g in 100 mL
   =500 mg in 100 mL
   =5mg/mL

4. You are treating a 40kg boy with a fractured femur requiring a femoral nerve block. The maximum safe dose of bupivacaine is 2mg/kg. What is the maximum safe volume of 0.5% bupivacaine, in mL?
   40 kg x 2 mg/kg = 80 mg
   =0.5 g in 100 mL
   =500 mg in 100 mL
   =1 mg in 100/500 mL
   =80 mg in 100/500 x 80 mL
   =16 mL

5. How many mL of 1:1000 solution would you need to obtain 0.3mg of adrenaline?
   1: 1000 = 1 g in 1000 mL
   1000 mg in 1000 mL
   =1 mg in 1 mL
   = 0.3 mg in 0.3 mL

6. An Australian colleague wishes to compare their formulation of bupivacaine with adrenaline. Their product consists of a 10mL amp of 0.25% bupivacaine with adrenaline 1:400 000 solution. How many micrograms of adrenaline is there in this ampoule?
   1: 400 000
   = 1 g in 400 000 mL
   =1000 mg in 400 000 mL
   =1 mg in 400 mL
   =0,25 mg in 100 mL
   =250 mcg in 100 mL
   =25 mcg in 10 mL

7. An Australian formulation of adrenaline is made up as a 1:10 000 solution. How many mg would you need to obtain 0.5mL?
   1 g in 10 000 mL
   1000mg in 10 000 mL
   1 mg in 10 mL
   0.1 mg in 1 mL
   0.05 mg in 0.5 mL

8. A 4-year old on your ward is in cardiac arrest. He weighs 12kg. The dose of Intravenous adrenaline is 10mcg/kg. How many mL of 1:1000 adrenaline will you need to draw up a single dose?
   10 mcg x 12 kg = 120 mcg
   1 g in 1000 mL
   1000 mg in 1000 mL
   1 mg in 1 mL
   1000 mcg in 1 mL
   1 mcg in 1/1000
   120 mcg in 1/1000 x 120
   =0.12 mL

7.2 Cycle I fourth year tutorial

Dosage calculation tutorial

9. Lignocaine is available in 5mL ampoules of 2%. How much lignocaine, in milligrams (mg), is in the amp?
   2% = 2g in 100 mL
   = 2000mg in 100mL (divide by 20)
   = 100mg in 5 mL
   So 100mg (in 5 mL amp)

10. You plan to suture a 60kg patient. Given the maximum safe dose of lignocaine is 3mg/ kg, what is the maximum safe volume, in mL, of 10% lignocaine solution that can be given?
    3mg/kg x 60 kg = 180 mg
    10% = 10 g in 100 mL
    = 10 000 mg in 100 mL
    So 1 mg in 100/10 000
    And 180 mg in 100/10 000 x 180
    =1,8 mL

11. A 4mL ampoule containing 0.5% bupivacaine contains how many milligrams per milliliter (mg/mL) of bupivacaine?
    0.5% = 0.5g in 100 mL
    =500 mg in 100 mL
    =5mg/mL

12. You are treating a 40kg boy with a fractured femur requiring a femoral nerve block. The maximum safe dose of bupivacaine is 2mg/kg. What is the maximum safe volume of 0.5% bupivacaine, in mL?
    40 kg x 2 mg/kg = 80 mg
    =0.5 g in 100 mL
    =500 mg in 100 mL
    =1 mg in 100/500 mL
    =80 mg in 100/500 x 80 mL
    =16 mL

13. How many mL of 1:1000 solution would you need to obtain 0.3mg of adrenaline?
    1: 1000 = 1 g in 1000 mL
    1000 mg in 1000 mL
    =1 mg in 1 mL
    = 0.3 mg in 0.3 mL

14. An Australian colleague wishes to compare their formulation of bupivacaine with adrenaline. Their product consists of a 10mL amp of 0.25% bupivacaine with adrenaline 1:400 000 solution. How many micrograms of adrenaline is there in this ampoule?
    1: 400 000
    = 1 g in 400 000 mL
    =1000 mg in 400 000 mL
    =1 mg in 400 mL
    =0,25 mg in 100 mL
    =250 mcg in 100 mL
    =25 mcg in 10 mL

15. An Australian formulation of adrenaline is made up as a 1:10 000 solution. How many mg would you need to obtain 0.5mL?
    1 g in 10 000 mL
    1000mg in 10 000 mL
    1 mg in 10 mL
    0.1 mg in 1 mL
    0.05 mg in 0.5 mL

16. A 4-year old on your ward is in cardiac arrest. He weighs 12kg. The dose of Intravenous adrenaline is 10mcg/kg. How many mL of 1:1000 adrenaline will you need to draw up a single dose?
    10 mcg x 12 kg = 120 mcg
    1 g in 1000 mL
    1000 mg in 1000 mL
    1 mg in 1 mL
    1000 mcg in 1 mL
    1 mcg in 1/1000
    120 mcg in 1/1000 x 120
    =0.12 mL

7.3 Tutorial 2 Cycles II & III

Dosage calculation Sample Tutorial Questions and Model Answers

1. Excerpt from the SAMF from the monograph on paracetamol reads :

Adult dose:
Oral. 0.5-1.0g, 4-6 hourly as required; maximum 4g in 24 hours
Preparations include:
Panadol®: tablets, 500mg

What is the lowest recommended effective dose that can be given?
0.5g. To work out how many tabs needed to give 0.5g, I put the amount in mg or g over the amount in of mg or g in 1 tablet = 0.5g/500mg, then I convert everything to the same units so 0.5g = 500mg so 500mg/500mg =1 tablet
What is the highest recommended effective dose that can be given?
1g. To work out how many tablets I put this amount over the amount in 1 tablet = 1g/500mg, then convert everything to the same units = 1000mg/500mg =2 tablets
After how long can the patient take another dose if the first dose was given at 10am?
After 4 hours, so 10h00 + 4 = 14h00=2pm, so can take another tablet after 2pm.
What is the most number of tablets (maximum dose) that can be taken in total in one day?
Maximum dose in g =4g. Need to convert this to tablets, so put this amount over the amount in 1 tablet = 4g/500mg, then convert everything to the same units, 4000mg/500mg = 8tablets

2. Excerpt from the SAMF from the monograph on paracetamol reads:
Paediatric dose: *neonates: 20mg/kg dose 8 hourly; maximum 60mg/kg/24 hours*
Preparations include: infant drops 60mg/0.6ml.
(The drops come with a dropper that holds 0.6ml, and there is a marking at the 0.3ml. mark for half a dropperful)
How many droppersful would you give to a 3kg baby?
20mg/kg dose x 3kg = 60mg dose so I'd give 60mg for every dose. I need to work out how many droppersful so I put this amount (60mg) over the amount in 1 dropperful. There are 60mg in 0.6mL and 1 dropperful =0.6mL so there are 60mg in 1 dropperful. So I put 60mg over 60mg . 60mg/60mg =1 so I need to give the baby one dropperful of medicine.
When could you repeat the dose if the first dose was given at 6am?
8 hourly: 06h00+8 = 14H00, so could give another dose at 2pm
What would be the maximum dose for this baby to receive in total in one day?
Max = 60mg/kg/24 hours = 60mg x 3kg in 24 hours (24 hours in 1 day so same as /day)
=180mg in 1 day
To work out dose in droppersful take 180mg and divide by the amount in 1 dropperful = 60mg so 180mg/60mg=3 droppersful
How many droppersful would you give a 1.5kg baby?
20mg/kg/dose = 20mg x 1.5kg =30mg in 1 dose
To work out amount in droppersful divide this by the number of mg in 1 dropperful = 60mg 30mg/60mg = ½ so give half a dropperful.

3. Excerpt from the SAMF from the monograph on ibuprofen reads:
Pediatric dose: *Pain or fever: 6months or 7kg: 5mg/kg 4 to 6 hourly*
Preparations include:
Brufen® *Paediatric suspension, 100mg/5mL*

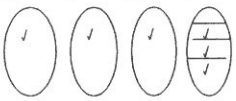
Work out the dose needed for a 10kg child. How many medicine spoonfuls should he receive?
5mg/kg x10kg =50mg. To work out how many medicine spoonfuls divide this by the amount in 1 medicine spoonful. 1 medicine spoonful =5mL, and the suspension contains 100mg /5mL = 100mg in 5mL. 50mg/100mg = ½ . so give the child half a medicine spoonful

4. A little boy has been prescribed 0.75mg digoxin bd. You think this is a bit high as the tablets are 0.25mg and this boy is only 15kg. You check the dose in the SAMF: for children, SAMF maintenance dose for paeds is 0.01mg/kg/day in 2 divided doses (adjusted according to serum levels)
a) What should the daily dose be?
0.01mg/kg x 15kg =0.15mg
b) What is the morning dose?
0.15mg/2 = 0.075mg
Note 0.075mg is 10 TIMES smaller than 0.75mg!
You alert the doctor and the dose is corrected.
c) What volume of digoxin paediatric elixir (0.05mg/mL) is needed to give this little boy the correct morning dose?
0.075mg needed
We have 0.05mg/mL solution
So 0.05mg in 1mL
And 0.075mg in x
0.05mg in1mL
Divide by 0.05 to get 1mg

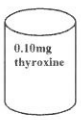
1mg in 1/0.05
X by 0.075 to get 0.075mg
So 1/0.05 x 0.075 = 1.5mL.

5. A girl of 56kg comes to the primary health clinic with blood in the urine. After taking her history and an examination she is diagnosed with bilharzia. You find the treatment for this condition in the Essential Drugs List (EDL).
The medicine praziquantel 40mg/kg is recommended
Note:
The strength of the tablet is 600mg and the tablet can be divided into quarters

a) How many tablets (whole and pieces) should she take to get the correct dose? Draw or write the answer in tablet form
40mg x 56kg = 2240mg needed
600mg in 1 tab
2240mg in x whole tabs
600mg in 1 tab
So 600mg x 2 =1200mg in 2 tabs
And 600mg x 3=1800mg in 3 tabs
And 600mg x 4=2400mg in 4 tabs
So need 3 tabs (4 tabs is too much)
3 tabs gives 1800mg but we need 2240mg
2240mg-1800mg = 440mg so we need as near to this number as possible
The 600mg tab can divide into quarters so each quarter piece is 600mg/4 = 150mg
1 piece = 150mg
2 pieces =150mg x 2 = 300mg
3 pieces =150mg x 3 =450mg and 450 very close to 440mg so give 3 pieces so your answer will be 3 ¼



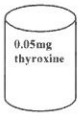
6.A woman is receiving thyroxine 225mcg (µg). The two bottles on the pharmacy shelf contain different strengths. The strength of each tablet is given on the bottles.
Note: these tablets are very small.
(Hint: the tablets are scored ***(this means that there is an indentation on the tablet allowing them to be cut in half)****).*
a) Fill in the number of tablets you would use from each of the following containers to give you the ***exact*** *correct dose.*
How many tablets from this bottle?



2 (that would 0.2mg = 200mcg)

Plus

How many tablets from this bottle?



half (that would give 0.025mg = 25mcg)

Total dose (2 x 100mcg) + (1/2 x 50mcg) =225mcg (other options also acceptable but **can't cut** 0.10mg into quarters it is too small)

7. An old man is getting gentamicin as part of his treatment for pneumonia. The doctor has written gentamicin 200mg daily. The amps (ampoules) come in 80mg only. There are 2mL in each amp. How many millilitres (mL) do you give?
Needs 200mg
There is 80mg in 2mL.
So divide by 80 to get 1
1mg in 2/80mL

X 200 = 200mg in 2/80 x200 = 5mL

8. A sick 3kg newborn baby (neonate) is kept warm against the mother's skin and breastfed while a transfer is arranged to hospital with the mother. As jaundice has been excluded and infection is suspected you decide to administer ceftriaxone according to the STG (excerpt follows:)

Drug treatment

If baby's tongue and lips are blue:

- Oxygen, using nasal catheter at 2 L/minute

If infection is suspected and jaundice has been excluded:

- Ceftriaxone, IM, 50 mg/kg into the lateral thigh

How would you prepare and administer this drug using a 250mg vial?

First need to work out how many milligrams of medicine I need to treat this baby. The dose needed is 50mg/kg and the baby weighs 3kg so I need to give 50mg/kg x 3kg = 150mg. I know I can mix this powder with 2mL of water for injection and it will dissolve because this amount is used to dissolve 250mg in the table from the EDL we used for diarrhea in the lecture. So I **add 2mL WFI** to give 250mg/2mL and I simplify this to get an amount for 1mL by dividing top and bottom by 2 = 125mg/1mL = 125mg/mL. I need to give 150mg so I say there is 125mg in 1mL. I use 1mg as a stepping stone and so I divide by 125mg to get 1mg and say there is 1mg in 1/125mL. I want 150mg so I step there by multiplying 1mg by 150, so there are 150mg in 1/125 x150mL =1.2mL so I **remove 1.2mL** from my vial and inject this IM into the baby

9. A new mother is diagnosed with syphilis. The mother is treated as per the EDL and the 3kg asymptomatic baby is given the following:

Newborn baby

Asymptomatic, well baby

- Benzathine benzylpenicillin (depot formulation), IM, 50 000 units/kg as a single dose into the lateral thigh

*What dose is needed in units? How would you reconstitute this medicine and what volume of the stock solution would you give to the baby? There are two vials available 1.2mu and 2.4mu and they may diluted with **4mL** WFI.*

We need to give 50 000 units/kg x 3kg = 150 000units.
There are two vials available 1.2mu and 2.4mu.
We could use a 1.2million unit (MU) vial as there would be enough powder in this vial to give us 150 000 units.
We would dilute this with 4mL of water for injection
So you would have 1.2mu in 4 mL
=1.2mu/4mL = 1 2000 000 units in 4mL
Use 1unit as a stepping stone (by dividing by the number 1 200 000) so
1 unit in 4/1200 000 mL
And step to 150 000 units by multiplying by 150 000
4/1200 000 x 150 000
=1/2 so give half a mL

10. A 20kg child has severe cellulitis and is treated in hospital with the following drugs. The reconstitution information is as follows:

Reconstitution

Constitute as follows:

***Penicillin G Sodium 5 MU*: add 3.5 ml Water for Injection to provide a concentration of 1 MU/ml.**

DRUG TREATMENT

Choice of intravenous or oral antibiotics depends on the severity of the condition.

Severe disease

For streptococci or haemophilus

- benzylpenicillin (Penicillin G), IV, 50 000 units/kg/dose, 6 hourly for 5 days

AND

For staphylococci

- cloxacillin, IV, 50 mg/kg/dose 6 hourly for 5 days

(For Cloxacillin you get 250mg and 500mg vials)
Reconstitute 500mg with 5mL WFI
a.) what amount of each medicine to you need?

For benzylpenicillin: 50 000 units/kg/dose x 20kg = 1000 000 units per dose
For cloxacillin 50mg/kg x 20kg = 1000mg per dose

b) what volume of each medicine would you remove from the stock solution and add to separate saline minibags?

For benzylpenicillin: 1 000 000 units needed (=1mu)
You have 5mu with a strength of 1mu/mL
1 000 000 units = 1mu
You have 1mu/mL so 1mu in 1 mL so need to revmove 1 mL.
From the reconstituted vial and put into the minibag.
For cloxacillin you need 1000mg
You have 500mg in one vial so you would need all the volume from 2 vials
Each 500mg is made up with 5mL
So 500mg in 5mL
So 1mg in 5/500mL
And 1000mg in 5/500 x 1000 = 10mL
So you need to make up 2vials with 5mL each and put the total of 10mL solution into the minibag

c) what drip rate would you set to run the bags in over 120minutes using an administration set with a drop factor of 60drops. mL?

50mL minibag and admin set 60drops/mL
So 60 drops/mL x 50mL.
120min
= 25drops/min

11. You plan to suture an 80kg patient. If the maximum safe dose of the local anaesthetic lignocaine is 3mg. kg what is the maximum safe volume, in mL, of 10% lignocaine solution that can be given? _____ mL

3mg/kg x 80kg
=240mg needed
You have 10% lignocaine
= 10g in 100mL
=1g in 10mL
=1000mg in 10mL
=100mg in 1mL
And 1mg in 1/100mL
And 240mg in 1/100 x240 =2.4mL

12. A 6 kg child is to be given 300 mg ceftriaxone. A volume of 3 mL containing the appropriate amount of antibiotic has been withdrawn from the stock solution and has been added to a 50 mL saline minibag. An appropriate infusion rate to administer this over 60 minutes, using a 60 drop per mL giving set, would be _____ drops per minute.

50mL x 60drops/mL
60min
=50drops/min

(you could also add the 3mL and take the volume to be 53mL and 53drops/min this would be more accurate and take exactly 60min to run in where the first answer would run in over slightly longer than 60min. Either answer is acceptable practically as the whole dose gets into the patient in close to an hour)

13. An 8-year old on your ward is in cardiac arrest. He weighs 30kg. The dose of intravenous adrenaline is 10ug kg. How many mL of 1:1000 adrenaline is in a single dose?

10ug/kg x 30kg
=300ug needed
You have 1: 1000 adrenaline
=1g in 1000mL
=1000mg in 1000mL
=1mg in 1 mL
=1000ug in 1mL
=1ug in 1/1000mL
And 300ug in 1/1000 x 300 =0.3mL

14. The steroid hydrocortisone 0.5mg kg. has been prescribed to treat an 11 year-old . 40kg boy. How many mLs are needed from a 2mL vial of hydrocortisone containing 100mg 2mL?

0.5mg/kg x 40kg
=20mg needed for the boy's dose
100mg in 2mL hydrocortisone
So 100mg/2mL
=50mg /1mL
50mg in 1 mL
And 1mg in 1/50mL
So 20mg in 1/50 x 20
=0.4mL

8. Assessment samples

8.1 Sample Dosage Calculation Questions for Formal Assessments

Answers in bold

Percentage

Lignocaine is available in 20mL ampoules of 1%. How much lignocaine, in milligrams (mg), is in the vial? _____

200mg

Ratio

What volume of 1:1000 solution would you need to obtain 0.5mg of adrenaline?

0.5mg

Mass/volume

Your team is doing an emergency intubation on a child using suxamethonium. The dose of suxamethonium in children is 2mg/kg. Suxamethonium is supplied in vials of 100mg in 2mL. To prepare this drug for use, one vial of suxamethonium is diluted with normal saline to 10mL total volume. How many mL of this solution are required for a single dose for a 15kg child?

3mL

Infusion rate

An 8kg child is to be given 800mg ceftriaxone. A volume of 8mL containing the appropriate amount of antibiotic has been withdrawn from the stock solution and has been added to a 50mL saline minibag. An appropriate infusion rate to administer this over 30minutes, using a 15 drop per mL giving set, would be _____ drops per minute.

25 or 29 drops/min

Percentage

You are treating a 25kg girl with a fractured femur requiring a femoral nerve block. The maximum safe dose of bupivacaine is 2mg/kg. What is the maximum safe volume of 0.5% bupivacaine, in mL?

10mL

Ratio

A 4-year old on your ward is in cardiac arrest. He weighs 16kg. The dose of intravenous adrenaline is 10mcg/kg. What volume of 1:1000 adrenaline will you need, to draw up a single dose?

0.16mL

Mass/vol

A 45kg female patient develops symptomatic bradycardia. You treat this with atropine, 20mcg/kg, given intravenously. How many mL of an atropine 1mg in 1mL solution will be required?

45kg 20mcg/kg = 900mcg

0.9mL

Infusion rate

A reconstituted 1.2g vial of Augmentin® is added to 200mL saline and must be run over at least 30 minutes. Using a 15 drops/mL giving set, the infusion rate is calculated to be faster than 1drop/second if the dose is to be given over this length of time. In order to decrease the rate to a more manageable one, the infusion time is increased to 60minutes. The infusion rate can now be set at._____

50 drops/min

Percentage

You plan to suture an 80kg patient. Given the maximum safe dose of lignocaine is 3mg/ kg, what is the maximum safe volume, in mL, of 2% lignocaine solution that can be given?

12mL

Ratio

How many micrograms (mcg) of adrenaline are there in a 20mL ampoule of 0.5% bupivacaine with adrenaline 1:200 000 solution?

100µg

Mass/volume

You plan to sedate a 15kg child with midazolam. A vial of midazolam has 15mg in 3mL. The intravenous sedation dose of midazolam for children is 0.1mg/kg. How many mL do you need to draw up?

0.3mL

Drip rate

If 0.6mL (containing 45 mg to treat a 3kg neonate) vancomycin solution is added to 50mL of 0.9% sodium chloride, then an appropriate infusion rate to administer this over 60minutes, using a 60drop per mL giving set, would be ____ drops per minute

50 drops/min

Percentage

You plan to suture an 80kg patient after surgical removal of a tumour. If the maximum safe dose of lignocaine is 3mg/ kg, what is the maximum safe volume, in mL, of 10% lignocaine solution that can be given? _____ mL

2.4 mL

Drip rate

A 6 kg child, whose white blood cell count has dropped after treatment with cancer chemotherapy, is to be given 300 mg ceftriaxone as part of an antibiotic regimen to prevent febrile neutropaenia. A volume of 3 mL containing the appropriate amount of antibiotic has been withdrawn from the stock solution and has been added to a 50 mL saline minibag. An appropriate infusion rate to administer this over 60 minutes, using a 60 drop per mL giving set, would be _____ drops per minute.

50 drops/min

(also acceptable if student uses volume of 53 mL → **53 drops/min**)

Ratio

An 8-year old on your ward is in cardiac arrest. He weighs 30kg. The dose of intravenous adrenaline is 10µg/kg. How many mL of 1:1000 adrenaline is in a single dose?

0.3mL

Mass/volume

The steroid hydrocortisone 0.5mg/kg, to be repeated depending on condition and response has been prescribed to treat an 11 year-old , 40kg boy in acute adrenal crisis.. How many mLs are needed from a 2mL vial of hydrocortisone containing 100mg/2mL?

4mL

Percentage
In order to treat 5 year old Angeline Govender's acute symptomatic hypocalcaemia, emergency treatment in the form of an intravenous infusion of calcium gluconate is commenced, with 5mL calcium gluconate 10% given by slow IV at the recommended rate. What mg dose of calcium gluconate has been given?
500mg

Percentage
How many micrograms (mcg) of adrenaline are there in a 20mL ampoule of 0.5% bupivacaine with adrenaline 1:200 000 solution?
100µg

Mass/vol
A woman with hypercalcaemia is to be given 40mg pamidronate by IV infusion. Three 15mg vials are each reconstituted with 10mL Water For Injection. How many mLs of solution must be withdrawn in total from the vials and added to the infusion?
26.7mL

Drip rate
The pamidronate solution is added to a 1L bag of saline. The infusion is to be given over 6 hours. An appropriate infusion rate to administer this over 6 hours, using a 15 drop per mL giving set, would be _____ drops per minute.
41drops/min (**43** also ok if student made volume 1030mL)

Percentage
You are excising a tumour from the leg of a 60kg woman and require a femoral nerve block. The maximum safe dose of bupivacaine is 2mg/kg. What is the maximum safe volume of 0.5% bupivacaine, in mL?
24mL

8.2 Cycle III Formative (informal) assessment: rational treatment decision

Imagine you just discovered that you have a risk factor for cardiovascular disease (e.g. High LDL cholesterol). A drug that will reduce this risk factor is available, and it has a low incidence of side effects. Consider the 3 following scenarios. Would you be willing to take this drug daily for the next 5 years if significant results from randomised placebo controlled trials showed that:

1. patients taking this drug for 5 years have 34% fewer heart attacks than patients taking placebo; **or**

2. 2.7% of the patients taking this drug for 5 years had a heart attack, comparing to 4.1% taking a placebo, a difference of 1.4%; **or**

3 if 71 patients took this drug for five years the drug would prevent one from having a heart attack. There is no way of knowing in advance which person that might be

8.3 Cycle III Typical Questions Assessment

1. Your team is doing an emergency intubation on a 15kg child using Drug A. The dose of drug A in children is 1mg/kg. Drug A is supplied in vials of 100mg in 2mL. To prepare this drug for use, one vial of drug A is diluted with normal saline to 10mL total volume. A

   A. The concentration of drug A undiluted is 50mg/mL

   B. The concentration of drug A diluted is 50mg/mL

   C. The concentration of drug A diluted is 8.3mg/mL

   D. One milliliter of the diluted solution is required for a single dose for a 15kg child

2. You are using drug B (available in 10mL vials of 0.5% strength) to provide local anaesthesia for a 20kg girl with a fractured femur. The maximum safe dose of drug B is 2mg/kg. C

   A. 10mL vials of 0.5% strength means that 0.5% of 10mL (i.e. 0.05mL) must be given to the child

   B. The child should get 500mg of drug B
   C. In 100mL of this solution, there is 0.5g of drug B
   D. The maximum safe volume of 0.5% drug B for this child is 4mL

3. A 4-year old on your ward is in cardiac arrest. He weighs 10kg. The dose of intravenous adrenaline is 10mcg/kg. 1mL vials of 1:1000 adrenaline are available.Choose the correct response. C

   A. There is 1g adrenaline in each vial

   B. In one litre of this adrenaline solution there would be 1 000µg adrenaline

   C. This patient needs 0.1mg adrenaline

   D. You will need to administer 1mL of the adrenaline solution

4. You plan to sedate a 5kg child with drug C. A vial of drug C has 15mg in 3mL. The intravenous sedation dose of drug C for children is 0.1mg/kg. C

   A. The concentration of this vial is 1.5mg/mL
   B. This child needs 50µg of drug C
   C. You need to draw up 0.1mL of drug C to administer to this child.
   D. If this vial were diluted further with saline to 6mL, then 2mL of the diluted solution would provide the required dose.

5. A reconstituted 1.2G vial of Augmentin® is added to 200mL saline and must be run over at least 30 minutes. A 15 drops/mL giving set is being used. A

A. An infusion rate of 100drops/min would allow the solution to run over 30 minutes but this rate would be too fast
B. An infusion rate of 50drops/min would allow the solution to run over 30 minutes
C. An infusion rate of 25drops/min would allow the solution to run over 30 minutes.
D. An infusion rate of 100 drops/min would allow the solution to run over 60 minutes

6. This picture shows an ampoule of adrenaline. It contains 1 mL of 1: 1000 adrenaline solution. You are treating a 10-year-old patient. The recommended intramuscular dose of adrenaline is 250µg C

A. There is 100µg adrenaline in the ampoule
B. There is 0.1mg of adrenaline in the ampoule
C. The volume of the solution in the picture needed for the patient is 0.25mL
D. The volume of the solution in the picture needed for the patient is 2.5mL

Use the picture and information below to choose the best option for the following two questions (7 and 8)

This picture shows an ampoule of lignocaine. It contains 10mL of 1% lignocaine solution. You need to administer this medicine as a local anaesthetic to a 40kg patient needing sutures (stitches). The maximum safe dose of lignocaine is 3mg/kg.

7. D

A. There is 0.1mg in an ampoule

B. There is 10g in an ampoule

C. There is 100µg in an ampoule

D. There is100mg in an ampoule

8. A

A. The maximum volume of the solution that can be administered safely is 12mL

B. The maximum volume of the solution that can be administered safely is 120mL

C. The maximum volume of the solution that can be administered safely is 120µL

D. The maximum volume of the solution that can be administered safely is 12 000mL

Use the picture and information below to choose the best option for the following two questions (9 and 10)

This picture is of a Mini-Jet® of atropine (this is a syringe containing a solution of atropine). There is 1mg of atropine in 10mLof solution. You decide to give a 40kg patient 20µg/kg to treat his bradycardia (slow heart rate).

9. A

A. The concentration of the solution is 0.1mg/mL

B. The concentration of the solution is 10µg/mL

C. The concentration of the solution is 1mg/mL

D. The concentration of the solution is 1µg/mL

10. C

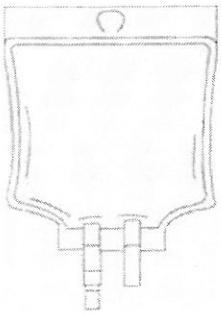
A. You give 0.2mL

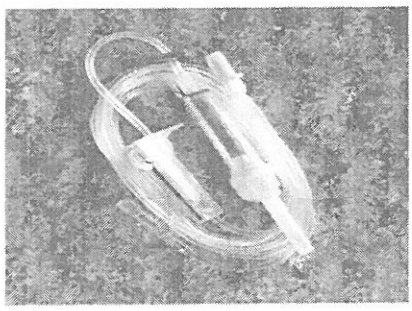
B. You give 2mL

C. You give 8 mL

D. You give 0.8mL

Use the picture and information below to choose the best option for the following two questions





Picture A shows a 50mL saline minibag. Picture B shows an administration set with a drop factor of 60drops/mL. A 10kg child has severe cellulitis and is treated in hospital with several drugs. One of these is penicillin G. You follow the reconstitution information to make a solution of Penicillin G containing 1MU/mL (i.e. 1 million units per millilitre). The South African Standard treatment guidelines recommend that 50 000 units/kg/dose of penicillin G be given for severe cellulitis together with other drugs.

12. C

A. A volume of 3 mL must be removed from the solution you reconstituted and added to the saline minibag

B. All the reconstituted solution must be added to the saline minibag

C. A volume of 0.5mL must be removed from the solution you reconstituted and added to the saline minibag.

D. A volume of 0.3mL must be removed from the solution you reconstituted and added to the saline minibag.

13. D

A. An appropriate drip rate to run the infusion solution in over 30 minutes using the minibag and administration set pictured above would be 50drops /min.

B. An appropriate drip rate to run the infusion solution in over 60 minutes using the minibag and administration set pictured above would be 25drops /min.

C. An appropriate drip rate to run the infusion solution in over 30 minutes using the minibag and administration set pictured above would be 25drops /min.

D. An appropriate drip rate to run the infusion solution in over 60 minutes using the minibag and administration set pictured above would be 50drops /min.

12. C

A. A volume of 3 mL must be removed from the solution you reconstituted and added to the saline minibag

B. All the reconstituted solution must be added to the saline minibag

C. A volume of 0.5mL must be removed from the solution you reconstituted and added to the saline minibag.

8.4 Cycle III Retrieval from Guidelines Questions

- The premixed combination of short and intermediate acting insulins, like all insulins currently available in South Africa, consists of 100units/mL

14. An unsuitable daily dose would be	A. A between 6 and 12 units
15. Siyabonga's daily insulin dose should be	B. B0.02-0.04 mL
16 An appropriate evening dose of insulin for Siyabonga is	C. C 0.6-1.2 mL
17. An appropriate morning dose for Siyabonga is	D. D4-8 units

Scenario for questions 14-17 which are matching type questions

Siyabonga Dlamini, a 5-year old male child presents with early stage insulin dependent diabetes mellitus with moderate hyperglycaemia (blood glucose 18.3 mmol/l). He weighs 20kg.

- The following is taken from the SAMF 7th Edition:

" Once over the initial period of ketoacidosis, an insulin regimen has to be chosen. This regimen should mimic normal blood insulin levels as far as possible, should preferably provide adaptability, and must fit the needs of the individual and suit the patient's circumstances. The initial requirements may be calculated on an unit/kg basis (0.3-0.6units/kg/day), and adjusted according to the patient's response."

- The following is taken from the Paediatric hospital level Essential Drugs List, and is the regimen chosen for Siyabonga's maintenance therapy.

  - Regimen 1: Two injections daily
    - a mixture (premixed combination) of short and intermediate acting insulins (before breakfast and the main evening meal)
    - The total daily dose is divided so that $^2/_3$ is given in the morning and $^1/_3$ in the evening

Regimen 1: Premixed 70/30		
Breakfast	intermediate acting ($^2/_3$ of dose) + short acting insulin ($^1/_3$ of dose)	$^2/_3$ of total daily dose
Supper	intermediate acting ($^2/_3$ of dose) + short acting insulin ($^1/_3$ of dose)	$^1/_3$ of total daily dose

Answers: 14 C 15 A 16 B 17 D

This case and excerpt relates to questions 18 to 21. Note that questions 18-21 are matching questions

An 8 kg baby has been diagnosed with PCP and prescribed co-trimoxazole (a combination medicine which comprises trimethoprim and sulphamethoxazole). Use the following excerpts from the Paediatric Hospital-level Essential drug list (EDL) and the Mims Desk Reference (MDR) to help you provide appropriate dosing information.

EDL Excerpt:
EDL Excerpt:

DESCRIPTION
PCP is an opportunistic respiratory infection most common in infants from 2–6 months. It presents with an acute onset of respiratory distress with minimal/absent chest signs in a child who is HIV exposed. Hypoxaemia and cyanosis are common features as the disease progresses.

DIAGNOSTIC CRITERIA
Clinical
- clinical suspicion in HIV exposed infants

Investigations
- oxygen saturation: usually less than 90% on pulse oximetry in room air
- chest X-ray
  - findings can vary
  - diffuse bilateral alveolar or interstitial infiltrate
- indirect immunofluorescence of nasal wash or tracheal aspirate/induced sputum may demonstrate Pneumocystis

NON-DRUG TREATMENT
- give oxygen, 1–2 L/minute via nasal prongs
- monitor saturation respiratory rate and other vital parameters
- supportive care, nasogastric feeds and intravenous fluids

DRUG TREATMENT
- trimethoprim/sufamethoxazole, IV, 5 mg/kg/dose of trimethoprim component 6 hourly for 5 days

When child improves follow with
- trimethoprim/sufamethoxazole, oral, 5 mg/kg/dose of trimethoprim component 6 hourly for 3 weeks

MDR excerpt:
(S4) IV INFUS [P/S] F/20.2/191
Trimethoprim 80mg, sulphamethoxazole 400mg/5mL.
706418-018: 5x5mL.
Dosage: Must be dil.1amp: 125mL infuse. sol.

MDR excerpt:

(S4) IV INFUS [P/S] F/20.2/191
Trimethoprim 80mg, sulphamethoxazole 400mg/5mL.
706418-018: 5x5mL.
Dosage: Must be dil.1amp: 125mL infuse. sol.

18. The amount of trimethoprim the baby should receive for each dose	A. 20mg
19. Amount of trimethoprim contained in a quarter of an amp of co-trimoxazole	B.200mg
20. The amount of sulphamethoxazole contained in the required volume of medication	C. 40mg
21. The amount of sulphamethoxazole contained in an amp of medication	D. 400mg

Answers: 18 C 19 A 20 B 21 D