Revision workshops in elementary mathematics enhance student performance in routine laboratory calculations

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Abstract

The ability to understand and implement calculations required for the molarity and dilution computations that are routinely undertaken in the laboratory are essential skills that should be possessed by all students entering an undergraduate life sciences degree. However, it is increasingly recognized that the majority of these students are ill equipped to reliably carry out such calculations. There are several factors that conspire against students' understanding of this topic; the alien concept of the mole in relation to the mass of compounds, and the engineering notation required when expressing the relatively small quantities typically involved, being two key examples. In this paper we highlight teaching methods delivered via revision workshops to undergraduate life sciences students at the University of Nottingham. The workshops were designed to; (a) expose student deficiencies in basic numeracy skills and remedy these deficiencies, (b) introduce molarity and dilution calculations and illustrate their workings in a step-by-step manner, and (c) allow students to appreciate the magnitude of numbers. Pre-workshop-post-workshop comparisons demonstrated a considerable improvement in students' performance, which attenuated with time. The findings of our study suggest that an ability to carry out laboratory calculations cannot be assumed in students entering life sciences degrees in the UK, but that explicit instruction in the form of workshops improves proficiency to a level of competence that allows students to prosper in the laboratory environment.

Key words: concentration, dilution, mass, molarity, molecular weight, moles, solution.

Introduction

The ability to perform the calculations necessary to accurately prepare solutions and carry out dilutions is a key requirement for all students of life sciences (a grouping which includes, but is not limited to biology, biochemistry, neuroscience, pharmacology, physiology), pharmacy and medicine. Given the importance of these skills, and the entry requirement to most undergraduate life sciences degrees in England of an A level in maths and/or chemistry, it should be safely assumed that all undergraduate students possess these relevant skills. This is not the case. A recent report the Times Higher Education (6) stated that 'students with A level maths have difficulty with even the simple calculations needed to prepare buffer solutions at a defined salt concentration.', in agreement with another report, which identified that 'even those (students) with top grades at A-level are woefully ill-equipped to study maths and science at university.' (5). The reasons for this deficit are probably several-fold but almost certainly include; (1) dislike or lack of interest in maths, a subject presumed to be difficult, and the worrying institutional acceptance of antipathy to maths shown by most students, (2) the combined difficulties of understanding the concept of the mole, and the magnitudes of the associated units e.g. pico, nano, micro etc., which requires an understanding of engineering notation, (3) the lack of appropriate context when teaching such methods at secondary school e.g. directions to make solutions upon which the student has no interest or investment, are not likely to be viewed as important and result in lack of involvement, and perhaps most worryingly of all (4) 'the modulization of A level, whereby there is no interlinking between the different elements of maths, but it is also because there is a race to the bottom at A-level by exam boards competing with each other about the ease with which students can achieve their grades.' (5).

A brief description may be expedient for those unfamiliar with the English educational system for children aged 5 to 18 years old. The National Curriculum is a set of subjects used by primary and secondary schools so children learn the same things at the same time, i.e. it is standardized across all English schools. It covers what subjects are taught and the standard children should reach in each subject (10). Children aged 5 to 11 attend primary school and progress through Year 6. Pupils aged 11 to 18 attend secondary school and progress from Year 7 to 13. Pupils aged 15 to 16 in Year 11 study for between 10 to 11 subjects at GCSE level. In year 12 pupils study 4 subjects at AS level, and dependent upon ability pupils can then enter Year 13 and undertake 3 subjects at A2 level. The aggregate marks for AS and A2 comprise the A level mark. Only 37% of 18 year olds take A levels. University requirements in England for entry into a Life Sciences degree is two A grades and a B grade at A level (although this can vary among Universities, and is subject to the widening participation scheme in which pupils from disadvantaged backgrounds are subjected to less strict entry requirements in order to redress social inequalities), where an A grade is 80% or above (A* are grades of 90% or above in the A2 component) and a B grade is between 70% and 79%. In 2013 850,752 students took A levels, and of those 10.2% took maths and 6.1% took chemistry. In A level maths 43% of pupils achieved A or A* grades and 22.2% achieved B grades, whereas in Chemistry 33.6% achieved A or A* grades and 27.1% achieved a B grade (4).

The concept of the mole is probably the major stumbling block to students' full understanding of the themes raised in this paper. The mole is an International Systems of Units (S.I.) definition base unit of the amount of a substance (17). The International Committee for Weights and Measures (CIPM) definition of a mole is, 'the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol".' (17). In addition: 'The definition of the mole also determines the value of the universal constant that relates the number of entities to amount of substance for any sample. This constant is called the Avogadro constant.' (17). These rather dry statements may not inspire the average student, but rephrasing these definitions in a form that relates the mole to molecular weight and mass, describes the mole in terms that can be readily understood. Thus, defining one mole of a chemical as equal to its molecular weight (MW) in grams, and by logical extension, that any given mass of compound divided by its molecular weight gives the number of moles of the compound, defines the mole relative to two properties that students should be familiar with: molecular weight and mass. Standard laboratory scales measure compounds in terms of mass, necessitating the inter-conversion between mass and moles. If a mass of a compound, containing a defined number of moles, is dissolved in a solvent the resulting solution contains the same number of moles, but convention dictates the solution is now defined in terms of Molarity (M). Molarity is the S.I. unit of concentration where a 1 Molar solution contains 1 mole of a solute per liter of solvent (17), hence 1 M is synonymous with 1 mole liter^{-1}. The relationships between mass, moles and molarity is illustrated in Figure 1.

The units used in such calculations can be a source of confusion, since the (usually) small quantities that are involved in everyday laboratory calculations are expressed using engineering notation, a version of scientific notation. In these calculations the units describing the *variables* are thus expressed in terms of moles, grams or liters, and scaled appropriately using engineering notation. In scientific notation numbers are expressed in the form a x 10^b, where the variable 'a' is a number between 1 and $9.\overline{9}$ and 'b' is the exponent, and describes the power to which ten is raised. In engineering notation the variable 'a' is a number between 1 and $999.\overline{9}$ and the exponent is divisible by three. Thus 0.00003 is 3 x 10^{-5} expressed in scientific notation, whereas it is 30 x 10^{-6} in engineering notation. Engineering notation is more convenient for our purposes since units of measure are generally preceded by a standard S.I. prefix (e.g. milli (x10^{-3}), micro (x10^{-6}), nano (x10^{-9}), pico (x10^{-12}) etc.).

Example calculations

One of the most basic tasks in the laboratory is to make a solution of a desired volume at a desired concentration from dry chemicals, where a known mass of a dry chemical is dissolved in a solvent, and made up to the desired volume. Standard practice in these procedures is to dissolve the dry compound in a volume of solution 80 to 90% of the desired volume, and once the chemical has completely dissolved, make up to the final desired volume in a volumetric flask (1). The key concept to understand in this type of calculation is the relationship between mass and moles described above. One mole of a compound is equal to the molecular weight in grams of the compound. For example the molecular weight of glucose is 180.16, thus one mole of glucose weighs 180.16 grams, 45.04 grams of glucose contains 0.25 moles of glucose, etc. Two common laboratory calculations are described below, which one would expect students entering a life sciences degree to understand, and be capable of carrying out with confidence.

1. Preparing a stock solution?

How would one make up 200 mls of a 4 M glucose solution? The first step in calculating molarity is to understand what 4 M glucose means. The symbol M is an abbreviation for moles per liter (moles l^{-1}). As the molecular weight of glucose is 180.16, converting moles to mass simply requires multiplication of the number of moles by the molecular weight.

4 moles x 180.16 grams $mole^{-1}$ = 720.64 grams

Hence 720.64 grams of glucose, made up to 1 liter constitutes a 4 M solution, i.e. 4 moles l^{-1}. However only 200 mls (0.2 l) is required, thus the mass required must be scaled appropriately, determined by what fraction of a liter is desired.

Consequently, the final step is to multiply the mass required by the volume:

= 720.64 grams x 0.2 = 144.128 grams.

Combining both steps results in the following relationship, which is used in all similar calculations:

$$\text{Mass required (g)} = \text{Molarity (moles } l^{-1}) \times \text{MW (g mol}^{-1}) \times \text{Volume (l)} \qquad \text{(Eq. 1)}$$

Some chemicals are hydrated i.e. are bound to water molecules e.g. $MgSO_4.7H_2O$, which complicates calculations. This topic is described in detail elsewhere (1).

2. Dilution of stock solutions

Stock solutions are a convenient and space-saving way of storing solutions: it is not necessary to make up a new solution each time the solution is required, rather a volume of an existing stock solution is diluted in an appropriate volume of solvent to produce the working solution. Practically, this is easier and quicker than making up a new solution from dry chemicals each time, and ensures reliability as the same stock solution can be used repeatedly. Dilution of a stock solution is a comparatively simple calculation based on proportion, the concept of which should be readily understandable. In these types of calculations there are four variables:

(1) the concentration of the stock solution (moles l^{-1})
(2) the volume of the stock solution (l)
(3) the desired concentration of the solution (moles l^{-1})
(4) the desired volume of the solution (l)

The relationship between these variables is as follows;
(1) Conc stock x (2) Vol stock = (3) Desired Conc x (4) Desired Vol
In this relationship the second variable (2) is the unknown, which is calculated by rearranging the equation thus:

$$\text{Vol stock (l)} = \frac{\text{Desired conc (moles l}^{-1}\text{) x Desired vol (l)}}{\text{Conc stock (moles l}^{-1}\text{)}} \qquad \text{(Eq. 2)}$$

Assessment of student ability to carry out routine molarity and dilution calculations

In our daily interactions with 1st year Neuroscience students it is evident that the majority are incapable of successfully carrying out the calculations described above. The Pharmacy degree at the University of Nottingham afforded an opportunity to compare the proficiency of students in carrying out these calculations, since whereas the Neuroscience students receive no instruction on laboratory based calculations, all 1st year Pharmacy students as part of the module Professional Skills 1: Introduction to Pharmacy Practice, which is designed to develop students appreciation of basic elements of Pharmacy practice via didactic lectures and workshops with a key component being training students to undertake numerical tasks of relevance to pharmacy, attend revision workshops which include calculations on molarity, dilutions and drug dosage. We therefore carried out an ad-hoc test of 55 1st year Pharmacy students and 35 1st year Neuroscience students. The students had no prior knowledge of the test, and were allowed twenty minutes to complete the test. The test comprised the following four questions, which were designed to test student understanding of the relationship between moles and mass, and dilution of stock solutions, the most likely calculations Neuroscience students will be required to carry out in their undergraduate laboratory studies.

1. What mass of glucose is required to make up 200 mls of a 4 M glucose solution? (MW glucose = 180).

2. What volume of a 2 M stock solution is required to make up 200 mls (0.2 l) of a 50 mM (0.05 moles l^{-1}) working solution?

3. What concentration of a stock solution of sodium lactate is required, such that injection of 200 μliters (200 x 10^{-6} l) of the stock solution into a rat with a blood volume of 19.5 ml (1.95 x 10^{-2} l) results in a blood lactate concentration of 10 mM (10 x 10^{-3} moles l^{-1})?

4. What is 90 mg dl^{-1} glucose expressed in moles l^{-1}?

The results of the test shown in Fig 2a, demonstrate that the Pharmacy students performed far better than the Neuroscience students with only 7.4% of Pharmacy students, but 42.9% of Neuroscience students achieving no correct answers. The cumulative index of the number of correct answers (where the x-axis indicates the accumulated number of correct scores, such that 3 indicates students who achieved 0, 1, 2 or 3 correct answers) shows a clear disparity between the two cohorts of students (Fig 2B). Further analysis of the data was carried out to determine if the Pharmacy students achieved significantly higher marks than the Neuroscience students. The percentage of students who correctly answered Questions 1 to 4 are plotted for each cohort in Fig 3A. A Mann Whitney test yielded a p value of 0.026 with Sum ranks of 25 (Pharmacy) and 11 (Neuroscience) indicating a significant difference. We next sought to determine if Neuroscience students who possessed A levels in chemistry and/or maths achieved higher marks than those lacking the qualification (Fig 3B). A Friedman test revealed no significant difference ($p = 0.80$), implying the possession of such qualifications was no predictor of performance.

Workshops

Given the varying backgrounds of students entering undergraduate life science degrees in England, an expectation of equivalent numeracy skills and their application to the field of chemistry is unrealistic. Thus, a series of revision workshops based on those delivered to Pharmacy students were given to the Neuroscience students in order to bring all students to an acceptable level of understanding and application in numeracy and pharmaceutical calculations, i.e. those calculations involved with molarities and dilutions.

The course of workshops we describe requires concessions from both academic staff and students. Students must be willing to acknowledge deficiencies despite top grades at A level, and be prepared for further study, and academic staff must be prepared to accept student limitations and expend the time and effort required to run such workshops in a non-judgmental manner.

As the first part of the workshop students were given a self-assessment calculation exercise (Appendix 1). Students were informed that a key part of the course is to ensure that all 1st year students have a good grounding in such calculations for their later studies, and the aim of these workshops is to ensure all students achieve the same level fundamental level. The students are instructed to carry out the 25 questions in 33 minutes without the aid of electronic calculators. Students are informed that the results from the assessment are known only to them and the instructor, and using data from all students will allow instructors to focus on areas that students struggle with most. After this workshop has been completed the results of the questions are described in a clear manner to ensure students understand that key steps/rules involved in the calculations. Several days later students then undergo a similar workshop (Appendix 2) under similar conditions in which molarity and dilution calculations are introduced in order to reinforce the basic arithmetical skills underlying calculations. As before the solutions to the questions are described in detail. Based on the student performance in this workshop, a selection process divided the students into one of the following three groups based on numerical ability.

a. Students who did all 20 questions in the 30 minutes and got no more than two wrong.

b. Students who did all 20 questions but took longer than 30 minutes or got more than two wrong or students who managed all but one or two questions.

c. Students who could not manage to do all 20 questions and/or felt that they needed additional support.

Each group then carries out the Pharmaceutical calculation workshop (Appendix 3), which involves more complex calculations concerning molarities. The solutions to the questions are described in detail until students are confident they can comfortably carry out the calculations. There is no time limit to this and the session ends when all students in the group are confident of their abilities. Ultimately the goal of these workshops is to (1) highlight where deficiencies lie and address these deficiencies, (2) allow students to understand definitions and rearranging equations, (3) get a feel for the magnitude of numbers.

Post workshop performance

After the students had completed the three workshops and were confident of their abilities they took a test comprising the following four questions. Students had 20 minutes to complete the test and calculators were allowed.

1. What mass of sodium chloride is required to make up 250 mls of a 40 mM solution? (MW sodium chloride = 58.4).

2. What volume of a 5 M stock solution is required to make up 250 mls (0.25 l) of a 150 mM (0.15 moles l^{-1}) working solution?

3. What concentration of a stock solution of sodium chloride is required, such that injection of 500 μliters (500 x 10^{-6} l) of the stock solution into a rat with a blood volume of 20 ml (2 x 10^{-2} l) results in a blood lactate concentration of 10 mM (10 x 10^{-3} moles l^{-1})?

4. What is 200 mg dl^{-1} calcium (MW 20) expressed in moles l^{-1}?

To determine the retention of the information delivered in the workshops students (now 2nd Year Neuroscience) were tested 9 months after the initial workshops with the same four questions as above (it is a safe assumption students will have forgotten the answers to the questions). The results shown in Fig 4 demonstrate the clear post-workshop improvement in proficiency among the students, but also an attenuation of performance after 9 months. A Friedman test demonstrated a significant effect ($p = 0.046$) between the pre and post-test achieving significance. A Mann Whitney test between pre test and 9 months post test revealed a p value of 0.026, implying that students retained the information delivered in the workshops to the extent that their performance was significantly different compared to the pre test results.

Discussion

This paper is intended to illustrate a method that can lead to improvements in student performance in laboratory calculations, with the first section suitable as a guide to carrying out such calculations. In our experience, many students undertaking undergraduate laboratory-based work do not fully comprehend the concept of the mole and its central role in the calculations required to prepare solutions. The Royal Society for Chemistry has highlighted the 'dumbing-down' of science taught at A level in England as a principal reason for students failing to achieve competency in key fundamental concepts of chemistry (8). Given this deficiency in secondary school teaching, coupled with the assumption of competency at the undergraduate level, students may be ill equipped to prosper in the laboratory environment. Mistakes resulting from inability to carry out these routine tasks can lead to faulty experiments in which it is extremely difficult to track down the sources of error (e.g. making up aCSF incorrectly in electrophysiology experiments). It can also lead to costly mistakes in which expensive reagents and antibodies are wasted, and in the case of medical and pharmacy students, mistakes could potentially be life threatening.

Our study identifies two key points. Firstly, students entering life sciences degrees in the UK are ill equipped to carry out routine laboratory calculations, that given the requirement for maths and/or chemistry at A level they would be expected to carry out with ease. Indeed we would extrapolate our findings from the narrow range of Neuroscience students described in this study to apply to students studying physiology, biology etc. To extrapolate our findings further, although we provide no evidence, it is likely that the issue we identify in this paper is relevant to students in all countries progressing to study college and undergraduate degrees. A comparison between Pharmacy students and Neuroscience students clearly showed a difference in ability, for example 42% of Neuroscience students achieved no corrects answers in the initial molarity questions, compared to only 7% of Pharmacy students (Fig 2). The reason for this difference is not that all Pharmacy students possess an A level in Chemistry since 30 out of 35 Neuroscience students possess the qualification. Indeed analysis of A levels possessed by Neuroscience students showed no advantage for students possessing A level chemistry and/or maths, compared to students who had neither qualification (Fig 3). This corroborates studies, which claim there is a lack of adequate rigor of maths in A level science subjects (3, 5). Secondly, the identified deficits in numeracy can be remedied with a course of workshops based around identifying and then subsequently correcting the deficits. The increased proficiency of Pharmacy students is certainly due to the mandatory teaching module attended by all students, a key factor in the basic training of Pharmacy students who must demonstrate professional proficiency at the end of 1st year in these type of calculation in order to progress in the course. The improvement in Neuroscience student performance after attending the revision workshops clearly demonstrated their effectiveness (Fig 4). However the information was not reliably retained with performance decreasing 9 months after the revision session suggesting that refresher courses should be offered every year.

While it is critical that students understand the theory behind these calculations, such that they can do them with pen and paper, we understand that under laboratory conditions, where multiple, repetitive calculations may be required, available technology in the form of desktop computers and smart phones can offer convenient and time saving solutions. There are a variety of suitable web-based programs available, which include, but are not limited to, SigmaAldrich.com (16), Promega.com (14), GraphPad.com (11), Tocris.com (18) and Functional Biosciences.com (7). All of the above programs carry out both molarity and dilution calculations except for Functional Biosciences, which is limited to dilution calculations. There are websites that contain either calculators (13) or tables for converting between conventional and S.I. units (9). In addition there are numerous apps for smart phones/iPad available via iTunes AppStores (search molarity or dilution). These include the following: Molarity (Free), DailyCalcs (Free) Solutions ($0.99), LabCal (Free), LabCalPro ($1.99), chemCalLite (Free), iSolutions (Free), Molarity Calculator ($1.99), MolarCalc ($1.99), Lab Solver ($1.99). Some of these programs carry out both molarity and dilation calculations, but some are limited to molarity calculations only (Solutions, LabCalPro, chemCalLite, iSolutions, Molarity Calculator and MolarCalc). Equivalent Android apps include Scientific Calculators ($0.99), AgileSciTools (Free) and Biolegend Lab Tools (Free), which are available for download from Android websites. We have written a rigorously tested stand-alone software program that is freely available and runs on Mac, Linux or Windows operating systems, and requires only one download to run on a desktop computer. The program is pre-populated with commonly used chemicals for ease of use, has a help page that offers succinct descriptions of the calculations available, and is available on request from the corresponding author. In addition there are a variety of useful books available which cover the topics described within this paper in detail of which the following are recommended (2, 12, 15).

In conclusion, our results indicate that students entering life science degrees at English universities are unlikely to be able to satisfactorily carry out the types of routine laboratory calculation involving molarities, dilutions and drug dosage that academic staff would expect, even if the students possess A grades at A level in maths and/or chemistry. These deficiencies are likely due to the ‘dumbing-down’ of content in maths A level, thus failing to prepare students adequately for the rigors of undergraduate life science degree courses. We describe a series of revision workshops that are mandatory for 1st year Pharmacy students at the University of Nottingham, given the importance of understanding such calculations to their professional proficiency, and demonstrate how introduction of the workshops to poorly performing Neuroscience students, significantly improves performance in this vital skill.

Disclosure statement.

The authors declare no conflict of interests

Appendix 1.

Questionnaire for testing basic mathematical skills. Students were required to complete the test in 40 minutes without the aid of a calculator.

1. 128 + 273	**401**
2. 12.8 + 97.56	**110.36**
3. 0.13 + 0.0083	**0.1383**
4. 735 – 63	**672**
5. 28.3 – 19.65	**8.65**
6. 46 × 567	**26082**
7. 4.8 × 6.3	**30.24**
8. 8.6 × 3.46	**29.756**
9. 250 ÷ 4	**62.5**
10. 459 ÷ 3	**53**
11. 456 ÷ 32	**14.25**
12. $\frac{2}{3} + \frac{1}{4}$	**11/12**
13. $\frac{2}{3} \times \frac{1}{5}$	**2/15**
14. $\frac{1}{6} \div \frac{2}{5}$	**5/12**
15. Express 0.0045 using standard form	**4.5 x 10^{-3}**
16. Express 1653 milligrams in grams	**1.653 g**
17. Express 0.045 grams in milligrams	**45 mg**
18. Convert 3 stones 2 pounds to kilograms. (1 stone = 14 pounds (lb), 2.2lbs = 1 Kg)	**20 kg**
19. Express the following number to 3 significant figures 1.37476502	**1.37**
20. Express $10^7 \times 10^{-2}$ as a power of 10	**10^5**
21. A stock solution containing 4.5% sodium chloride is diluted to make a solution of 0.9% sodium chloride. What is the dilution factor?	**5**
22. Re-arrange the following equation to make m the subject $6 = \frac{m}{n} + k$	**m = n(6-k)**

23. Sodium hydroxide has a molecular mass of 40. What concentration will a solution have if 20g of solute is dissolved in water to produce 500ml of solution? **1 M**

24. Substance A has a relative molecular mass of 128. How many moles are there in 32g of solid? **0.25 mol**

25. Simplify: Log 2 + Log 3 **Log 6**

Appendix 2.

Questionnaire for testing more advanced mathematical skills and molarity/dilution type calculations.

1. Express 29642 milligrams in grams **29.642 g**

2. Express 0.097 grams in milligrams **97 mg**

3. Sodium hydroxide has a molecular mass of 40. What (molar) concentration will a solution have if 30mg of solute is dissolved in water to produce 125μl of solution? **6 M or 6 Molar**

4. Substance J has a relative molecular mass of 224. How many moles are there in 28g of solid? **0.125 moles or 0.125 mol**

5. You have 250ml of erythromycin suspension 125mg/5ml. How many grams of erythromycin are there in 75ml? **1.875 g**

6. A cream contains 3%w/w of diclofenac. How many milligrams of diclofenac are there in 50g of cream? **1500 mg**

7. A pre-filled syringe contains 2ml of adrenaline 1 in 1,000. What volume must be given to provide a dose of 0.3mg? **0.3 mL**

8. How many millilitres of concentrated chloroform water are required to produce 500ml of chloroform water? **12.5 mL**

9. How much alimemazine syrup (7.5mg/5ml) is required to treat a patient requiring a dose of 15mg three times a day for 3 days? **90 mL**

10. How much castor oil is required to make 450ml of an emulsion containing 40%v/v of castor oil? **180 mL**

11. Complete the formula below for the preparation of 250ml of a solution of potassium permanganate, in water, from which a patient can dilute twenty millilitres up to a total volume of 2000ml with water to produce a potassium permanganate solution of 1 in 10,000.
    Potassium Permanganate = **2.5 g or 2 500 mg**
    Water for preparations = **to 250 mL**

12. En-De-Kay Fluotabs contain 1.1mg sodium fluoride. 2.2mg of sodium fluoride provides 1mg of fluoride Ions (F^-). How many tablets would you provide to give a 500 microgram dose every other day for 12 weeks? **42**

13. You are supplied with a solution of erythromycin 100mg/ml. Complete the formula below for the preparation of 280ml of a solution containing erythromycin 125mg/5ml.
    Erythromycin 100mg/ml = **70 mL**
    Water for preparations = **210 mL or "to 280 mL"**

14. You are required to supply 200g of Elocon™ ointment 1 to 4. Complete the formula below for such a supply.
    Elocon™ ointment = **40 g**
    White soft paraffin = **160 g or "to 200 g"**

15. A child weighing 30kg is required to receive a dose of cefaclor 20mg/kg daily in three divided doses. What volume of a 125mg/5ml suspension should be given for each dose? **8 mL**

16. How many grams of Dermovate™ Ointment are contained in 750g of a 1 in 5 dilution? **150 g**

17. You are required to make up a preparation to the formula below. What is the percentage v/v of alcohol in the final preparation? **13.5% v/v**

Solution A	10ml	(Containing 40% v/v Alcohol)
Solution B	50ml	(Containing 15% v/v Alcohol)
Solution C	40ml	(Containing 5% v/v Alcohol)

18. How many millilitres of water must be added to 100ml of an 27%w/v stock solution of sodium chloride to prepare sodium chloride solution 0.9%w/v? **2900 mL**

19. A patient uses 250ml of a 1:1000 solution of a disinfectant footwash, four times daily, for seven days. How many grams of the disinfectant have been used? **7g**

20. A five-year-old child weighing three stones and two pounds (3st 2lb) has been prescribed tobramycin 25mg three times a day. The BNF dose for a child is 3-5mg/kg daily in divided doses. Is the prescribed dose appropriate? (1 stone = 14lb, 1kg = 2.2lb) **Yes**

Appendix 3.
Questionnaire for testing advanced molarity/dilution type calculations.

1. Express 5683 milligrams in grams **5.683 g**

2. Express 0.007 grams in milligrams **7 mg**

3. Sodium hydroxide has a molecular mass of 40. What (molar) concentration will a solution have if 10g of solute is dissolved in water to produce 500ml of solution? **0.5 M or 0.5 Molar**

4. Substance J has a relative molecular mass of 132. How many moles are there in 26.4g of solid? **0.2 mol or 0.2 moles**

5. You have 325ml of ampicillin suspension 250mg/5ml. How many grams of ampicillin are there in 80ml? **4 g**

6. A cream contains 0.5%w/w of hydrocortisone. How many milligrams of hydrocortisone are there in 50g of cream? **250 mg**

7. A pre-filled syringe contains 1ml of adrenaline 1 in 1,000. What volume must be given to provide a dose of 0.6mg? **0.6 mL**

8. How many millilitres of concentrated peppermint water are required to produce 200ml of double strength peppermint water? **10 mL**

9. How much morphine sulphate solution (10mg/5ml) is required to treat a patient requiring a dose of 45mg four times a day for 7 days? **630 mL**

10. Duraphat™ toothpaste contains sodium fluoride in a concentration that equates to 2,800 parts per million of fluoride ions (F^-). 1mg of fluoride ions is provided by 2.2mg of sodium fluoride. What strength, expressed as %w/w, of sodium fluoride is contained in Duraphat™ Toothpaste? **0.616%**

11. Complete the formula below to produce 600ml of a solution containing propranolol 40mg/5ml. Your stock solution contains 200mg/5ml.

Propranolol 200mg/5ml = **120 mL**
Water for preparations = **480 mL or "to 600 mL"**

12. Complete the formula below for the preparation of 120ml of a solution of potassium permanganate, in water, from which a patient can dilute 10 millilitres up to a total volume of 1500ml with water to produce a potassium permanganate solution of 1 in 10,000.
    Potassium Permanganate = **1.8 g or 1800 mg**
    Water for preparations = **to 120 mL**

13. You are supplied with a solution of Oramorph™ concentrate 20mg/ml. Complete the formula below for the preparation of 140ml of a solution containing Oramorph 10mg/5ml.
    Oramorph Concentrate = **14 mL**
    Water for preparations = **126 mL or "to 140 mL"**
14. How much almond oil is required to make 750ml of an emulsion containing 20%v/v of almond oil? **150 mL**

15. You are required to supply 240g of Propaderm™ ointment 1 to 3. Complete the formula below for such a supply.
    Propaderm™ ointment = **60g**
    White soft paraffin = **180 g or "to 240 g"**

16. You add 1g of coal tar to 50g of Lassar's paste. How much coal tar, in grams, is contained in 10g of the final product? Quote your answer to 3 decimal places. Lassar's paste contains 5% w/w coal tar. **0.686 g**

17. You mix 200g of a 10% w/w ichthammol ointment, 450g of 5% ichthammol ointment and 350g of white soft paraffin (diluent). What is the percentage of ichthammol in the finished product? **4.25% w/w**

18. How many grams of Synalar™ Ointment are contained in 75g of a 1 in 5 dilution? **15 g**

19. An adult requires 750mg ciprofloxacin twice each day for 7 days. How much of a 250mg/5ml suspension would you provide? **210 mL**

20. You are required to make up a preparation to the formula below. What is the percentage v/v of alcohol in the final preparation? **38.6% v/v**
    Solution A 50ml (Containing 80% v/v Alcohol)
    Solution B 150ml (Containing 22% v/v Alcohol)
    Solution C 300ml (Containing 40% v/v Alcohol)

21. How many millilitres of water must be added to 250ml of an 18%w/v stock solution of sodium chloride to prepare sodium chloride solution 0.9%w/v? **4750 mL**

22. You are required to make up a syringe containing glucose for a syringe driver. You have a 100ml ampoule containing glucose 50% w/v. How much of this solution must you draw up (and then dilute) to produce 250ml of a solution containing 100mg/ml? **50 mL**

23. If an antibiotic injection contains 5% w/v of the drug, how many millilitres of diluent should be added to 5ml of the injection to prepare a solution containing antibiotic 5mg/ml? **45 mL**

24. A patient uses 50ml of a 1:1000 solution of an antiseptic mouthwash, four times daily, for seven days. How many grams of the antiseptic have been used? **1.4 g**

25. A doctor requires their patient to receive tobramycin sulphate 1mg/kg of body weight. The patient weighs 9 stone 6 pounds. How many millilitres of tobramycin sulphate injection 80mg/2ml should be administered to achieve this dosage? NB 1 stone = 14 pounds, 1kg = 2.2 pounds. **1.5 mL**

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Figure Legends

Figure 1

The relationship between key definitions and units. All compounds have a molecular weight (MW) determined by its chemical composition. A. The mass of the compound is converted to the equivalent number of moles by dividing the mass of the compound by its molecular weight. B. The mass of compound dissolved in a solute is expressed as a Molarity i.e. number of moles per liter of solution. Stock solutions can be diluted to yield working solutions.

Figure 2

Summary of student scores in questionnaires designed to test competency in molarity/dilution calculations. A. The number of students achieving 0 to 4 questions correct for both the 1st year Pharmacy and Neuroscience students. B. Cumulative scores for students scoring 0 to 4 questions correct clearly shows the superior performance of the Pharmacy students compared to the Neuroscience students. Values adjacent to columns indicate scores rounded to the nearest percentage point.

Figure 3

A question-by-question comparison of Pharmacy and Neuroscience students' performance. A. In all 4 questions a higher percentage of Pharmacy students achieved the correct answer compared to Neuroscience students. B. A comparison of Neuroscience students based on A level performance demonstrated no advantage for students possessing A level chemistry and/or maths compared to students lacking these qualifications.

Figure 4

Neuroscience student performance was improved after attending workshops. After attending workshops student performance improved in all 4 questions, but this improvement was attenuated 9 months after the workshops.