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Evaluation of numeracy skills in first year pharmacy undergraduates 1999–2005

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Abstract
There is growing concern within the profession of pharmacy regarding the numerical competency of students completing their undergraduate studies. In this 7 year study, the numerical competency of first year pharmacy undergraduate students at the School of Pharmacy, Queen's University Belfast, was assessed both on entry to the MPharm degree and after completion of a basic numeracy course during the first semester of Level 1. The results suggest that students are not retaining fundamental numeracy concepts initially taught at secondary level education, and that the level of ability has significantly decreased over the past 7 years.

Keywords: *Numeracy, calculations, MPharm, assessment*

Introduction

Within the last decade, there has been an unprecedented shift in emphasis within undergraduate degree programmes in the development of key transferable generic skills, such as those relating to IT, verbal and written communication, interpersonal, and numerical skills. Although not specifically referred to within the Royal Pharmaceutical Society of Great Britain's "Indicative Syllabus for UK Pharmacy Degree Courses", competency in numeracy is a prerequisite for successful completion of the undergraduate MPharm degree. In fact, numerical concepts provide the foundation for a substantial proportion of the degree course content, from pharmaceutics to pharmacotherapy, and drug design to dispensing. Furthermore, the pre-registration examination lays strong emphasis on numerical competency.

Against this backdrop, and despite independent assessment of teaching quality by the Quality Assurance Agency, there are growing concerns that pharmacy students having completed their MPharm degree do not demonstrate the necessary numerical skills required of the pharmacy profession (Nathan, 2000). For example, in a study performed to determine baseline clinical competence of a cohort of preregistration trainees, competency in numerical skills was identified as the major weakness, with only 15% of trainees being able to calculate a loading dose despite being given all the relevant data and equations (McPherson, Davies, & McRobbie, 1999). Given that poor numeracy skills are now a common feature in many undergraduate scientific and medical disciplines, there is a consensus emerging that the problems do not stem directly from the quality of university training but rather as a result of primary and secondary educational policies and methods adopted over recent years. Anecdotal evidence would suggest that students entering university today have a lower level of numerical competency than their counterparts in the past.

As part of the undergraduate MPharm course in the School of Pharmacy, Queen's University of Belfast, first year students must complete a first semester "Skills Development for Pharmacy Students" module. The module aims to develop skills in statistical methods, IT, report writing, oral communication, numeracy, study skills and examination technique. Since 1999, the authors have had responsibility for developing and coordinating an introductory numeracy course as part of this Level 1 Skills module, the aim of which is to assess and develop students'

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Table I. Student profile: mean A-level score and numeracy assessment results.

Year of entry	Number of students	Mean A-level score	Initial assessment mean percentage score ± SD	Final assessment mean percentage score ± SD
1999	106	28.0	54 ± 14	70 ± 13
2000	104	27.8	47 ± 15	73 ± 15
2001	123	28.5	46 ± 14	75 ± 15
2002	131	397*	41 ± 13	68 ± 15
2003	129	392*	40 ± 14	71 ± 15
2004	139	422*	41 ± 14	74 ± 16
2005	142	426*	40 ± 15	72 ± 16

* Replaces average A-level scores information and encompasses various qualification types upon entry.

competency in basic mathematical/numeracy concepts as applied to the subject of pharmacy. In this study, the authors report their findings based on results obtained from 1999 to 2005.

Methods

Initial numeracy assessment

Since 1999, all first year pharmacy students enrolled on the MPharm undergraduate degree course at the School of Pharmacy, Queen's University of Belfast, have completed an initial numeracy assessment paper containing 21 questions designed to test their numerical competency over a wide range of general mathematical, chemical and pharmaceutical calculations (Appendix 1). The first eight questions cover basic mathematical concepts (solving and rearranging equations, standard form, algebra, percentages, line equations, base 10 logarithms); questions 9–14 cover basic chemistry-type calculations (moles, density, molarity, balancing and using chemical equations, empirical formula); questions 15–18 cover common units of concentration, and questions 19–21 pharmaceutical-type calculations relating to concentration and dilution. With the exception of the final two questions, the assessment was pitched at a GCSE and GCE level, as detailed in current mathematics and chemistry syllabi. Students completed the assessment in a 1 h period under examination conditions, and were provided with the relative atomic masses for relevant atoms. Questions 1–10 were answered without use of a calculator; for the remaining questions, the students had the option to use a calculator.

The papers were marked by two members of academic staff according to a clear and simple marking scheme and returned to students within 1 week. For each question, a score of either zero or one was awarded, and the final score was presented to the students as a mark out of 21. To score one mark in a particular question, the student needed to provide the correct numerical answer *and*, where appropriate, the correct units. If either the numerical *or* the units component of the answer were incorrect, or both, a zero mark was awarded for the question. Also, where a question contained more than one part, both parts had to be answered correctly in order to score one mark. Although this marking scheme may seem harsh, one of the learning objectives of the numeracy course was to instill in the students the importance of including units in their final answers. The pass mark for the assessment was 40%.

Feedback and numeracy course

One week after receiving their marked initial assessments, a feedback session was scheduled with the class to discuss the assessment paper, and to highlight areas were the students performed poorly. During the following 4 weeks, 2 h numeracy workshops (with accompanying worksheets) and a 3 h directed study programme (using materials provided electronically on "Queen's Online" (QOL), the university's virtual learning environment) were organized to provide the students with opportunities to develop their numerical competency in the general areas covered by the initial assessment. Also, additional self-study material was provided on QOL and (http://www.qub.ac.uk/pha-old/numeracy/) numeracy website was designed to complement the course.

Final numeracy assessment

Six weeks after the initial assessment, the students completed a final numeracy assessment paper (Appendix 2), the structure of which closely resembled the initial paper. The students were not told in advance that the initial and final papers were similar. Using the same marking scheme and pass mark as described previously, the papers were marked by the same two academic staff and returned to students within 1 week.

Results and discussion

Students entering Queen's to study pharmacy are among the most highly qualified in the UK, as reflected in average A-level scores on entry (Table I). Minimum entrance requirements are AAB in GCE A-levels, including chemistry and at least one from

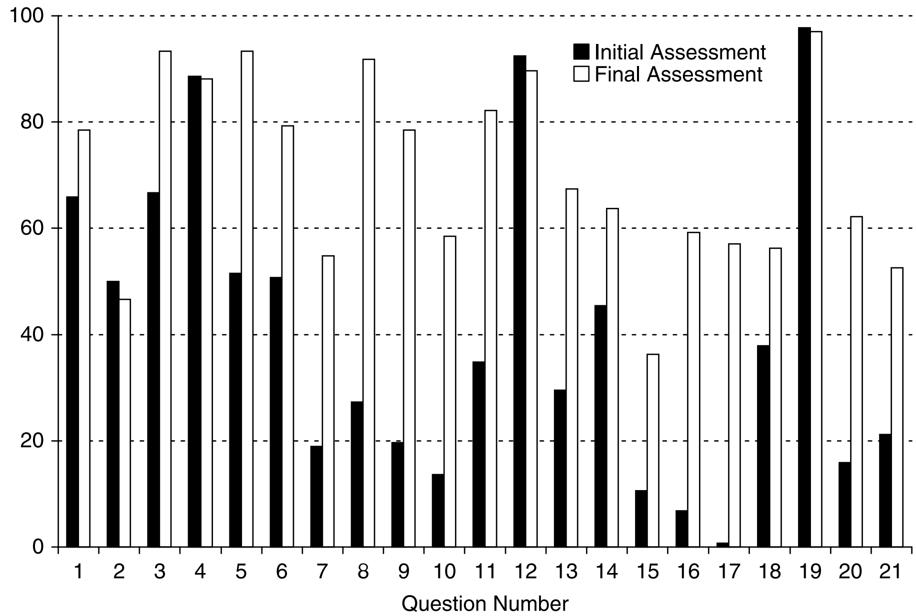

Figure 1. Histogram detailing the percentage of students responding correctly to each of the 21 questions in the 2003 initial and final numeracy assessment paper.

biology, mathematics and physics. A grade C or above in GSCE mathematics is also required.

The student marks in the initial and final numeracy assessments (mean $\pm$ SD) are summarised in Table I for the years 1999–2005. For the initial assessment, the highest mean score (54%) was observed in 1999, and the lowest mean scores (40–41%) were recorded in each of the years from 2002 to 2005. The results of statistical ANOVA testing using the Tukey-Kramer multiple comparisons test indicated that significant differences were observed on comparing the results for 1999 with all other years ($p < 0.01$ for year 2000; $p < 0.001$ for years 2001–2005). Similarly, significant differences were observed on comparing the results for 2000 with other years (not significant for year 2001; $p < 0.05$ for years 2002, 2004 and 2005; $p < 0.01$ for 2003). Results obtained from 2001 onwards showed little or no significant differences when compared with results from later years.

Figure 1 shows a histogram describing the percentage of year 2003 students responding correctly (i.e. scoring one mark) to each of the 21 questions in both the initial and final numeracy assessments. Entirely similar histograms trends were observed in all other years, suggesting that: (i) the specific areas in which the students' displayed strengths and weaknesses did not change over the course of this study; and (ii) not surprisingly, students performed significantly better in the final assessment taken after they completed the numeracy course. A more detailed description of the major conceptual problems encountered by students in responding to each question is presented in Table II. However, some general comments can also be made. In the initial assessment paper, only eight questions were answered correctly by 50% or more of the students; Q1–6, Q12, and Q19. Q1–6 and Q19 were of a standard equivalent to GCSE maths, while Q12 (balancing a hydrocarbon combustion reaction) is covered at both GCSE and GCE level chemistry. The questions that students had most difficulty with, as reflected in poor scores both in the initial and final assessments, were Q7 (straight line equation, GCSE maths), Q10 (moles/density/volume, GCE chemistry), Q15–17 (part per concentration notation, GCE chemistry), Q18, 20 and 21 (pharmaceutical dilutions, not covered at GCSE/GCE).

To examine any changes in student competency between years, a comparison of the results from the initial assessment was made. Table III shows the drop in number of students giving the correct answer for each question as a percentage relative to the results of the 1999 cohort. Eighteen of the 21 questions showed a drop in student performance in at least four of the 6 years studied. Of the 18 questions which showed a drop in student performance, six showed a drop in the number of students giving the correct response by more than 50% in each of the last 3 years studied relative to 1999. The mean drop in number of students responding correctly in the initial assessment shows an increase from 18 to 20% in the first 2 years after 1999 to 33% in each of the last 2 years.

Results from the initial test give an assessment of ability on entry, prior to any third level instruction by our staff. Overall, there is a clear drop in the performance of students in each year relative to 1999. In 2000 and 2001, the mean drop in percentage of students giving correct answers was 19%, which increased to 33% for the 2004 and 2005 cohort. Despite the overall

Table II. Summary of the main sources of error for each question in the assessments.

Question number	Main source(s) of error	Question number	Main source(s) of error
1	Inability to cross-multiply; did not notice that the fractions could be easily simplified	11	Calculation of moles; problems with dilution aspects
2	inability to cross-multiply; unable to multiplying sides of equation by −1	12	Generally well answered; some problems with balancing the equation
3	Rounded up numbers rather than include all significant figures	13	Unsure of definition of empirical formula; % w/w units; ratios
4	Unable to perform multiplication of brackets without a calculator	14	Problems determining which compound was in excess; misunderstanding of equation stoichiometry
5	No or incorrect units provided; uncertainty in working with ratios	15–17	Poor understanding of "part per" concentration notations
6	Could not formulate the problem mathematically; some confusion with percentages	18	Did not add the two masses to produce the total weight of 110 g
7	Could not provide the general equation for a straight line; problems with calculating gradients and determining the intercept	19	Simple multiplication errors
8	Lack of understanding of the basic concept of a logarithm	20	Could not formulate the problem mathematically; confusion over % w/w units
9	Lack of understanding of the basic concept of a mole, particularly as applied outside of chemistry	21	Could not formulate the problem mathematically;
10	Could not recall the definition/equation for density; no or incorrect units provided		

Table III. Percentage of correct answers provided for individual questions for years 2000–2004 relative to the 1999 values; questions are listed in order of mean drop.

Question number	2000	2001	2002	2003	2004	2005	Mean drop
17	85	60	36	88	69	54	65
16	47	65	50	54	60	53	55
20	49	38	47	61	64	61	53
21	42	45	57	48	54	49	49
13	14	32	45	52	53	55	42
14	18	38	51	41	49	47	41
8	9	39	35	53	50	55	40
15	48	−15	44	58	48	56	40
11	37	29	28	39	40	42	36
9	24	30	39	40	33	39	34
7	4	16	38	32	39	43	29
18	26	19	33	22	30	20	25
10	29	−21	26	39	33	38	24
1	3	23	19	18	20	17	17
6	16	−2	21	24	14	25	16
3	4	5	26	15	25	20	16
2	−2	−1	0	15	12	15	6
12	−2	−2	5	1	−1	2	0
5	−19	−15	5	10	4	9	−1
19	−5	0	3	−3	−1	−3	−1
4	−1	−3	−2	−2	−1	−2	−2
Mean	20	18	29	34	33	33	

downward trend, four questions show no drop or a small increase (less than 2%) in performance. These questions relate to balancing simple equations and arithmetic. All the questions showing less than a mean 20% drop in performance examine ability in arithmetic, basic algebra or balancing simple equations. The six questions showing the highest mean drop in student performance over the 6 years studied (more than 40% drop) cover, with one exception, topics not directly on the A-level or GCSE syllabi. These questions cover basic dilutions and concentrations of pharmaceutical formulations, requiring application of GCSE-level skills to a type of problem not previously encountered. Interestingly, a question regarding empirical formula determination, covered at GCSE, also showed a mean drop in performance of more than 40%.

Conclusion

The results of initial and final assessments indicate that despite similar A-level scores for each year under study, students entering the MPharm programme showed a significant drop in performance in basic numeracy questions which examine ability to apply basic knowledge to new situations in the period 1999–2005. Students performed at a similar level in questions, which closely resemble GCSE or A-level style questions across the period studied. After delivery of a numeracy course as part of the MPharm programme, student performance improved significantly and to a similar level in each of the years studied. Future studies will seek to assess students in various Schools of Pharmacy throughout the UK.

References

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Appendix 1: Initial numeracy assessment paper

Initial numeracy assessment	Do not use a calculator for questions 1–10.

1. Solve the following equation for x

$$\frac{0.24}{0.04} = \frac{510}{x}$$

2. Rearrange the following equation to give an expression for f

$$f = \frac{d^2 - l^2}{4d}$$

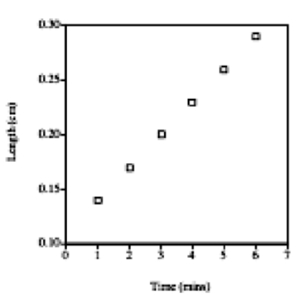
3. Convert the following numbers into standard form, i.e. e $\times 10^2$
   (a) 0.000345 (b) 672891

4. Find the following sum:
   $(2.00 \times 10^2) + (0.10 \times 10^4)$

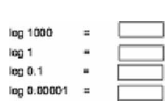
5. Bob the Builder uses a mortar for bricklaying consisting of 3 parts sand to 1 part cement. How much cement does he require to fill a hole measuring 110 cm $\times$ 100 cm $\times$ 10 cm with mortar?

6. A Ford Mondeo loses 60% of its initial value after 3 years. If after 3 years it is worth £6400, what was its initial cost?

7. Calculate the gradient of the straight line in the graph, and determine the equation of the line.



8. Provide answers in the boxes below.



9. How many moles of water are in a 1.0 litre bottle of water?

10. Ethyl alcohol has the formula CH_3CH_2OH. It's density is 0.80. (a) How much does 1 mole of ethanol weigh? Its density is 0.80. (b) What volume will this mole occupy?

11. Calculate the molarity of a solution prepared by dissolving 5.85 g sodium chloride (molar mass = 58.5 g mol^{-1}) in water and diluting to 200 ml.

12. Balance the following equation: $C_3H_6 + O_2 \rightarrow CO_2 + H_2O$

13. A compound was found to contain 66.01% w/w carbon, 8.29% w/w hydrogen and 25.68% w/w nitrogen. Determine its empirical formula.

14. Given the equation below, if 38.5 g of HCl and 80 g of NaOH are reacted, what weight of NaCl will be produced? $HCl + NaOH \rightarrow NaCl + H_2O$

15. A rabbit weighing 2 kg dies and falls into a lake. If the lake holds 10^9 kg of water, what is the concentration of rabbits in ppb in the lake?

16. A sample of water is found to contain 10 ppm benzene as a contaminant. What weight of benzene is present in 10 litres of this water?

17. 0.2 g of sodium hydroxide (molar mass = 40 g mol^{-1}) is dissolved in a litre of water. What is the concentration of the solution expressed in molar units and in ppm?

18. If 10 g glucose is dissolved in 100 g water, what is the weight % of the glucose in the resulting solution?

19. A patient is asked to take one tablet four times daily for 28 days. How many tablets will the pharmacist dispense?

20. How many grams of ibuprofen must be added to 100 g of a gel to produce a gel containing 10% w/w ibupralen?

21. "Codeine Linctus" is a cough mixture containing codeine phosphate in solution (concentration of 15 mg/5 ml). A more dilute mixture (3 mg/5 ml) is used for children, and may be prepared by diluting the concentrated mixture. What volumes of the liquid vehicle and the concentrated mixture need to be added together to prepare 100 ml of the dilute mixture?

Appendix 2: Final numeracy assessment paper

Final numeracy assessment	Do not use a calculator for questions 1–10.

1. Solve the following equation for x

$$\frac{5.5}{0.5} - \frac{8x^2}{96x}$$

2. Rearrange the following equation to give an expression for b

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

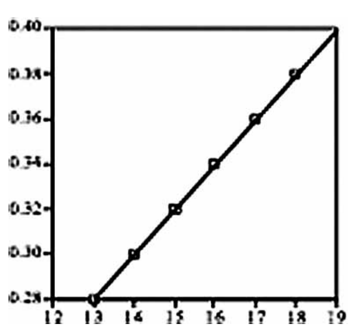
3. Convert the following numbers into standard form, i.e. $a \times 10^b$
   (a) 0.101 (b)1101020

4. Find the following sum:
   $(4.22 \times 10^2) + (0.10 \times 10^2)$

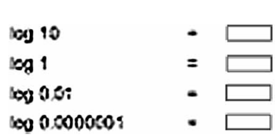
5. To make a cheesecake topping you need: 18 parts by weight of natural yogurt, 18 parts sugar, 8 parts soft Philadelphia cheese, and 1 part lime juice. How much cheese is required to make 450 g of topping?

6. A semi-detached house increases in value by 50% over 5 years. If after 5 years it is worth £135,000, what was its initial cost?

7. Determine the gradient of the straight line in the graph below, and provide the equation of the line.



8. Provide the answers in the spaces provided.



9. A steam iron has a capacity of litres 15 ml. How many moles of water can it hold?

10. Benzaldehyde has the formula C_6H_5CHO. Its density is 1.04. (a) How much does 2 mol of benzaldehyde weigh? (b) What volume will these 2 mol occupy?

11. Calculate the molarity of a solution prepared by dissolving 29.3 g of sodium chloride in water and diluting to 4 l (relative formula mass of sodium chloride-58.5 g mol^{-1})

12. Balance the following equation:
    $C_6H_{10} + O_2 \rightarrow CO_2 + H_2O$

13. A compound was found to contain 83.37% C, 9.15% H and 7.48% N. Determine its empirical formula.

14. Given the equation below, if 50 g of HCl and 40 g of NaOH are reacted, what weight of NaCl will be produced? $HCl + NaOH \rightarrow NaCl + H_2O$

15. When 5 g of sugar is added to a mug containing 245 g of coffee, what is the concentration of sugar in the coffee in parts per million?

16. A sample of river water is found to contain 15 ppb toluene as a contaminant. What weight of toluene is present in 1 litre of this water?

17. 0.66 g of sodium hydroxide (relative formula mass = 40 g mol^{-1}) is dissolved in a litre of water. What is the concentration of the solution expressed in molar units and in ppm?

18. If 20 g of sodium chloride is dissolved in 100 g water to make a saline solution, what is the weight percentage of sodium chloride in the resulting solution?

19. A patient is asked to take three tablets three times daily for 14 days. How many tablets will the pharmacist dispense?

20. How many grams of metronidazole must be added to 80 g of a gel base to produce a gel containing 10% w/w metronidazole?

21. What is the concentration of dextrose in a solution prepared by mixing 100 ml of 10% w/w dextrose 50 ml of 20% w/w dextrose, and 100 ml of 5% w/v dextrose?