19

Improving Mathematics Understanding in the Pharmacy Undergraduate Program

Kathryn Browning

Department of Pharmacy
University of Copenhagen

Introduction

Numeracy is an important component of the pharmacy career path. Errors in routine calculations such as drug dosages and dilutions can lead to disastrous consequences. Whilst studying the concentration of morphine infusions for a neonatal critical care unit prepared by in-house pharmacists, Parshuram et. al. found errors of greater than 10% in in 65% of samples (Parshuram et al., 2003). 6% of these samples contained two-fold errors or greater (Parshuram et al., 2003).

It is critical that the Pharmacy education effectively prepares students to be confident and precise in calculation and lab skills. It has been noted by course leaders that undergraduate students throughout the program are lacking the mathematics skills necessary for successful completion of the pharmacy education. The mismatch between teacher's expectations and the student's maths abilities is a complaint that is neither new or confined to health sciences (Cox, 2001). Upon entering university education, the level of experience varies dramatically with some students unfamiliar with simple rearrangement of equations and percentage calculations whilst others are already comfortable with the majority of the first year curriculum. The quality and level of teaching of mathematics prior to university level has been found to be well-correlated to the success of the Pharmacy student (Conn et al., 2018). Within the Department of Pharmacy at KU previous research found that mathematics grades upon admission was the key competency that predicted the success of the student at the end of the first year (Bendahl et al., 2004). As the Danish mathematics high school curriculum is something that we, as university teachers, cannot easily affect, requirements on teaching are greatly complicated especially in first year courses. Devising the most appropriate level to begin teaching is vital to strike a balance between catering to the students that are struggling with the material whilst ensuring the advanced students are challenged. This, coupled with teachers who are not specialised maths lecturers, leads to a discrepancy in the teacher's expectations and the student's actual mathematical abilities (Batchelor, 2004).

A decline in student's mathematical abilities entering university level has been well documented (Hawkes et al., 2000; Lawson, 2003; Lawson et al., 2003) and in some cases has led to a reduction in the mathematical content of university courses (Norris, 2012). Furthermore, students risk disengagement from the scientific topics due to a lack of confidence in their maths abilities, especially when comparing themselves to students with higher mathematical competence (Lawson et al., 2003). Anecdotally, this leads to an overreliance on computer algebra systems (such as Maple) in these less confident students and a reduction in critical assessment when analysing computed answers. Other universities have tried to fix this in a number of ways from small scale project such as the preparation of study guide leaflets (Study guides, 2018) to university wide centres of mathematic support (Lawson et al., 2003; Croft et al., 2014). In this project the aim is to assess the student's mathematical skills upon entering the pharmacy program and point them in the direction of learning which can strengthen their weaker areas. This was achieved by preparation of two online self-assessed quizzes, one, which contained familiar algebra style questions, and a second that focussed on routine calculations from the degree.

Description of the course

The pharmacy education consists a three-year bachelor course followed by a two-year masters course, completion of both elements qualifies the student as a Pharmacist. At Copenhagen University the admission requirements for the bachelors program are: Danish A, English B, Mathematics A and one of the following combinations: Physics B and Chemistry B, Physics B and Biotechnology A, Chemistry B and Geoscience A or Chemistry B, Biology A and Physics C. In addition in 2018, an entrance exam score of 8.2 for quota 1 and 7.3 for quota 2.The bachelors program is taught between two departments, Institut for Farmaci (IF) and Institut for Lægemiddeldesign og Farmakologi (ILF), with IF taking many of the courses related to physics and traditional pharmacy and ILF holding courses on biology and organic chemistry. Previously there was a dedicated mathematic course, however, this was recently removed, and the content integrated into all courses within the first year.

Intervention

In order to provide a self-assessment exercise for the first year BSc students, two quizzes were prepared as part of the Kemiske Principper (SFABIF117U) course. These quizzes were designed to test the student's maths abilities in two main areas, traditional maths and pharmaceutical maths. The first quiz contained more traditional, algebra based questions including addition of fractions, rearranging algebraic equations, differentiation and integration. Due to limitations of the Absalon quiz structure, it was hard to input formulae as answers, therefore, multiple choice questions (MCQ) were used. The second quiz aimed to test the students application of the tradition maths to pharmaceutical, real-life, situations, for example dilution of a stock solution, calculation of concentration, mole fractions etc. Only the first question, a question on rounding and significant figures (Appendix A, 1b) was multiple choice, all other questions were constructed response questions (CRQs) consisting of numerical answers. After completing each quiz, the answers were provided with a detailed description (in English) of how to obtain the correct answers, a link to the relevant pages of the maths textbook for the course was also provided (Monk et al., 2010). The test was not mandatory, however, a deadline was set one week after the introductory lecture to encourage the students to complete the tests before becoming too distracted by course material.

Results and discussion

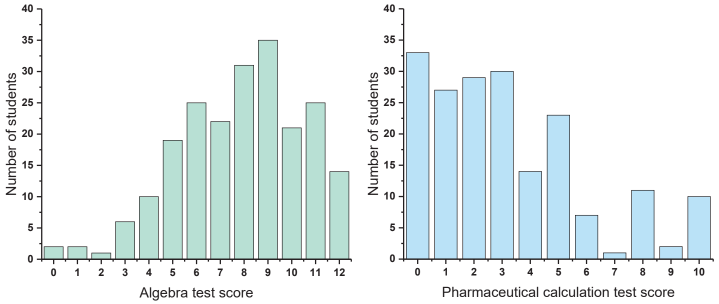

Fig. 19.1. Test score data for the two online quizzes, left, data for the algebra test (n=213) and, right, data for the pharmaceutical calculations test (n=190).

Results from the online quizzes were collated in Absalon and the resulting test scores presented in figure 19.1. The mean test score for the algebra test was 66% compared to 32% for the pharmaceutical calculations. The distribution of test scores for the algebra test shows a traditional Gaussian distribution indicating that the level of the test was well pitched to be challenging yet still achievable for the mathematically confident students. The results for the pharmaceutical calculations (figure 19.1, right) were surprising, many students (33) failed to score above zero and the number of students obtaining higher grades was much lower, as seen by a drop in mean test score of 34%. Figure 19.2 shows the scores for both tests for each student after removal of students who only completed one of the two tests (n=187). The size of the bubble indicates the amount of students with the same score pairing. A student scoring highly in the algebra exam will not necessarily succeed at the pharmaceutical calculation test, in fact, it is clear that almost all students scored worse on the pharmacy test compared to the algebra test.

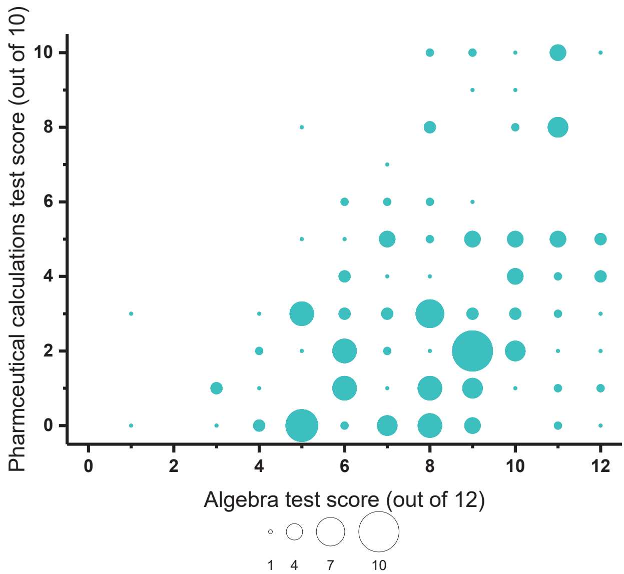

Fig. 19.2. Comparison of test scores of the two quizzes, larger bubbles indicate more students with the same score in both tests.

The hypothesis upon devising the study was that mathematics was too abstract for many of the pharmacy students, as the course provides a high content of applied science, and therefore questions that were more closely related to real life maths applications would be easier to answer. However, having recently left high school education, the more traditional algebra style questions seem to be easier. There are a number of other reasons why the test scores may differ between the tests, the most striking is the difference in answer format. The nature of the algebra test answers (the need to input formula) necessitated the use of MCQs whereas the pharmaceutical test contained CRQs. MCQ tests suffer from a ‘guessing effect’, where scores are artificially inflated due to the student assessment of the most likely answer. However, Triantis et. al. found that two similar tests could be compared by using a scoring rule which corrected a considerably smaller difference between MCQ and CRQ tests (k parameter of 0.3) (Triantis et al., 2014). Therefore, there must be other factors affecting the difference in scores between the two tests.

Another possible difference between the two tests is language, although the introduction of the test was translated to Danish, the questions (and answer explanations) were written in English. Due to the applied nature of the questions in the pharmaceutical test, the average number of words per question was 24, excluding values, formulas and units, compared to only 5 words for the algebra test. As English is not the main language of instruction in the course, this may have added to the lower average score for the pharmaceutical test. In future iterations of this quiz, all questions will be translated to Danish; however, the feedback will be kept in English as it refers to an English textbook.

Finally, each student was able to attempt the test 3 times, with feedback given after the first attempt on how to attempt the question. As the pharmaceutical test was the second test, the students may have become wise to this feedback and are not applying themselves in the first attempt, rather just waiting to read the feedback and attempting it on the second try. In fact, 128 students attempted the pharmaceutical quiz a second time and the mean test score increased to 84% (from 34%). In comparison, 96 students retook the algebra test and the mean test score increased from 66% to 91%.

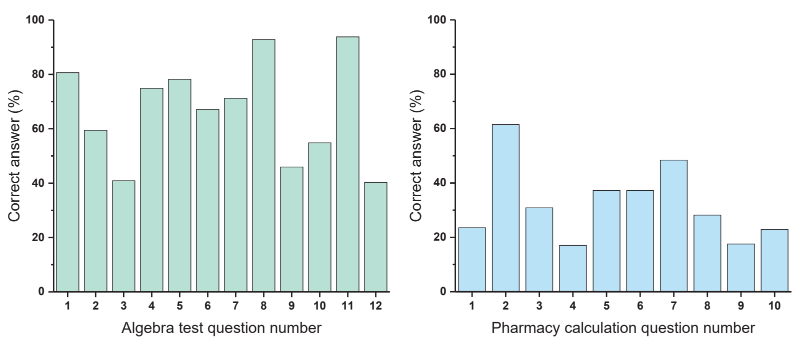

Fig. 19.3. Percentage of correct answers for each questions in, left, the algebra test (n=213) and, right, the pharmaceutical calculations test (n=190).

The results, figure 19.3, were further analysed to assess particular concepts that the students struggle with, shown as the percentage of correct answers for each question in Appendix A. In the algebra test, there are a number of questions that scored below 60% correct, indicating that students have problems with rearranging equations especially when they contain natural logs and integration. Two questions scored over 90 percent indicating good knowledge of the addition of powers and differentiation. The results for the pharmaceutical test show that all concepts need to be improved, however, there are 5 questions which scored particularly badly with less than 30% correct. Suggesting the students struggle with units, significant figures, using equations and calculating the gradient of a graph. Interestingly 62% of students were able to answer question 2 correctly, calculating the amount of a drug in an aliquot of stock solution. The second highest score (48%) was for question 7, calculation of a percentage yield.

The multiple choice answers to the algebra test were chosen from simple mistakes e.g. order of rearrangements, miscalculation of positive and negative numbers etc. For the pharmaceutical calculation test, it was not clear which mistakes would be most common. As a CRQ style was used for this test, the most common wrong answers were recorded and can now be used to develop a MCQ test with realistic answers in the coming years.

As discussed by Batchelor, the best improvement in mathematical competence is obtained when self-assessment tests are coupled with a focussed lecture addressing the major issues of the cohort directly (Batchelor, 2004). From the results gathered from these tests, an additional lecture starting in 2019 will be added to the curriculum in the second week of the semester directly after the deadline, which will be tailored to focus on the issues of the incoming cohort.

Conclusion

In conclusion, two tests were developed to assess the mathematics abilities of incoming pharmacy students. Results showed that the algebra test was a useful refresher for students with a normal distribution in test results and an average score of 66%. The pharmacy test was less successful (average score 32%) and highlighted a number of issues in the understanding of maths when applied to 'real-life' situations. Key problems were discovered in the use of units, significant figures and rounding errors. More emphasis in the first year of the degree should be placed on improving student's confidence in their mathematics abilities and how to use mathematics as a tool for pharmacy. The incorrect answers gathered for the pharmaceutical test will be used to develop a multiple choice test so that the two tests can be better compared in future years. Due to the findings of this research a 45 minute lecture will also be added to the chemical principles course in 2019. Specific problems identified from the tests will be the focus whilst attempting to ground the content in everyday occurrences in the pharmaceutical career track, i.e. dilutions of drugs to correct dosages or preparation of accurate documentation for FDA approval.

References

Batchelor, H. (2004). The importance of a mathematics diagnostic test for incoming pharmacy undergraduates. *Pharmacy Education, 4*(2).

Bendahl, L., Jensen, H., Larsen, S. W., Thomsen, A. E. & Østergaard, J. (2004). Undersøgelse af farmaceutstuderendes grundlæggende kemiske og matematiske færdigheder efter 1 . år.

Conn, K. M., Birnie, C., McCaffrey, D., & Brown, J. (2018). The relationship between prior experiences in mathematics and pharmacy school success. *American journal of pharmaceutical education, 82*(4), 6257.

Cox, W. (2001). On the expectations of the mathematical knowledge of first-year undergraduates. *International Journal of Mathematical Education in Science and Technology, 32*(6), 847-861.

Croft, A. C., Lawson, D. A., Hawkes, T. O., Grove, M. J., Bowers, D., & Petrie, M. (2014). sigma–a network working. *Mathematics Today, 50*(1).

Hawkes, T., & Savage, M. D. (2000). Measuring the mathematics problem. *London: Engineering Council.*

Lawson, D. (2003). Changes in student entry competencies 1991–2001. *Teaching mathematics and its applications, 22*(4), 171-175.

Lawson, D., Croft, A. C., & Halpin, M. (2003). Good practice in the provision of mathematics support centres. *LTSN Maths, Stats & OR Network*.

Norris, E. (2012). *Solving the maths problem: international perspectives on mathematics education.* Royal Society for the encouragement of Arts, Manufactures and Commerce.

Monk, P., & Munro, L. J. (2010). *Maths for chemistry: a chemist's toolkit of calculations*. Oxford University Press.

Parshuram, C. S., Ng, G. Y, Ho, T. K., Klein, J., Moore, A. M., Bohn, D., & Koren, G. (2003). Discrepancies between ordered and delivered concentrations of opiate infusions in critical care. *Critical care medicine*, 31(10), 2483-2487.

Study guides, Learning, University of Kent. Available at: https://www.kent.ac.uk/learning/resources/study-guides.html?tab=pharmacy-calculations. (Accessed: 31st December 2018)

Triantis, D., Ventouras, E., Leraki, I., Stergiopoulos, C., Stavrakas, I., & Hloupis, G. (2014, April). Comparing Multiple-Choice and Constructed

Response Questions Applied to Engineering Courses. In *International Conference on Computer Supported Education* (pp. 130-140). Springer, Cham.

A

Appendix 1a Test Questions – Algebra

1. Simplify the following to solve for x.

   $\boldsymbol{y = 5x - 4x + 7x + 1}$

   a. $x = \frac{y+1}{8}$

   b. $x = \frac{y-1}{8}$

   c. $x = \frac{y}{8}$

   d. $x = y - 8$

2. What is the value of: $\frac{1}{a} + \frac{1}{b}$?

   a. $a^b b^a$

   b. $\frac{b+a}{ab}$

   c. $\frac{1}{ab}$

   d. $\frac{1}{a^2 b^2}$

3. Multiply out the brackets and solve for x.

   $\boldsymbol{y = 4(c - x^2)}$

   a. $x = 4c - \sqrt{y}$

   b. $x = \sqrt{\frac{y-4c}{4}}$

   c. $x = \sqrt{\frac{c-4}{y}}$

   d. $x = \sqrt{c - \frac{y}{4}}$

4. Multiply out the brackets in the following equation.

   $\boldsymbol{ab(x - y)}$

   a. $ax - by$

   b. $ax + bx - ay - by$

   c. $aby + abx$

   d. $aby - abx$

5. Factorise the following equation.

   $\boldsymbol{x^2 + 4x + 3}$

   a. $(x - 3)(x - 1)$

   b. $(x + 3)(x + 1)$

   c. $(x - 4)(x - 3)$

   d. $(x + 4)(x + 3)$

6. Reduce the equation to the form y=mx+c.

   $\boldsymbol{4y = -4x + 12}$

   a. $y = -x + 12$

   b. $y = -x + 3$

   c. $y = x - 3$

   d. $y = x + 4$

7. Calculate the slope of a line between the following co-ordinates.

   $\boldsymbol{(-5, 4)\ and\ (7, 12)}$

   a. 4

b. $\frac{1}{4}$

c. $1,5$

d. $\frac{2}{3}$

8. Simplify the following equation.

   $\mathbf{10^3 x 10^5}$

   a. 10^8

   b. 1^9

   c. 100^8

   d. 10^{15}

9. Isolate x.

   $\boldsymbol{y = \ln x^2}$

   a. $x = \sqrt{\ln y}$

   b. $x = \sqrt{e^y}$

   c. $x = e^{\sqrt{y}}$

   d. $x = \sqrt{\ln\left(\frac{1}{y}\right)}$

10. Simplify the following equation.

    $\boldsymbol{\ln 5x - \ln 5}$

    a. $\ln \frac{1}{x}$

    b. e^{5x-5}

    c. $\ln 25x$

    d. $\ln x$

11. Differentiate the following equation.

    $\boldsymbol{y = x^3 + 4}$

    a. $2x^2 + 3$

    b. $x^2 + \frac{4}{3}$

    c. $3x^2$

    d. $3x^4 + 4$

12. Integrate the following equation.

    $\boldsymbol{\frac{dy}{dx} = 2x^5}$

    a. $\frac{2}{6}x^6$

    b. $\frac{x^6}{3} + c$

    c. $10x^4 + c$

    d. $10x^6 + 5$

    e. $2y \cdot x^5 + 5x$

Appendix 1b Test Questions – Pharmaceutical Calculations

1. A chemist makes 0,37g of potassium chloride. The molar mass of KCl is 74,5 g mol^{-1}. What is the amount of KCl made (mols)? Please provide answer in scientific notation.
   a. 4.966 x 10^{-3} mol
   b. 0,005
   c. 4,9 x 10^{-3} mol
   d. 5,0 x 10^{-3} mol

2. If a 300 mL bottle of a product contains 15 g of ingredient A, how much is there in 5,0 mL?
   (Hint: $\frac{m_1}{V_2} = \frac{m_2}{V_2}$)

3. How much glucose is needed to make up 750 mL of a 5% w/v concentration?
   (Hint: $m = \frac{c}{V}$)

4. How much of ingredient A should you add to 100 mL of a 10% v/v

solution to increase it in strength to a 20% v/v solution?

5. During the course of a reaction, the entropy S changes from -15,1 J K^{-1} mol^{-1} to -32,5 J K^{-1} mol^{-1}. Calculate the numerical (no units) value of ΔS.

6. The molar mass of sulphuric acid is 98 g mol^{-1}, and the molar mass of water is 18 g mol^{-1}. What is the total combined mass of 2 moles of sulphuric acid dissolved in 12 moles of water?

7. A chemical reaction occurs. The initial amount of the limiting reagent is 1,25 mol. After reaction and purification, the amount of product is 0,85 mol. What is the percentage yield?

8. We define the gradient (slope) of a graph as:

$$gradient = \frac{y_2 - y_1}{x_2 - x_1}$$

Calculate the slope that passes through the following co-ordinates, (4,1 , 3,0) and (5,5 , 12,0)

9. The ideal gas equation:

$$pV = nRT$$

relates volume, V, of an ideal gas to temperature, T, the amount of gas, n, and the pressure, p. R is the gas constant.

Rearrange the equation to make n the subject and find the amount of moles of gas in a 24,0 L container at 298 K and 5 x atmospheric pressure (5,00 atm).

Hint: The gas constant, R, is 0,082057 L atm K^{-1} mol^{-1}

10. The mole fraction, x, of a substance is defined as:

$$x = \frac{amount\ of\ x(in\ mols)}{total\ number\ of\ mols}$$

A mixture contains 3 components, A, B and C. The mixture comprises 4,5 mol of A, 3,2 mol of B and 11,6 mol of C. What is the mol fraction of B, x_b.