

INSTRUCTIONAL DESIGN AND ASSESSMENT

Impact of a Required Pharmaceutical Calculations Course on Mathematics Ability and Knowledge Retention

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Submitted June 13, 2012; accepted February 18, 2013; published August 12, 2013.

Objective. To assess doctor of pharmacy (PharmD) students' mathematics ability by content area before and after completing a required pharmaceutical calculations course and to analyze changes in scores.

Methods. A mathematics skills assessment was administered to 2 cohorts of pharmacy students (class of 2013 and 2014) before and after completing a pharmaceutical calculations course. The posttest was administered to the second cohort 6 months after completing the course to assess knowledge retention.

Results. Both cohorts performed significantly better on the posttest (cohort 1, 13% higher scores; cohort 2, 15.9% higher scores). Significant improvement on posttest scores was observed in 6 of the 10 content areas for cohorts 1 and 2. Both cohorts scored lower in percentage calculations on the posttest than on the pretest.

Conclusions. A required, 1-credit-hour pharmaceutical calculations course improved PharmD students' overall ability to perform fundamental and application-based calculations.

Keywords: pharmaceutical calculations, mathematics skills, assessment

INTRODUCTION

As one of the most trusted professionals in the United States, pharmacists are expected to dispense medications accurately.¹ This expectation includes correctly performing pharmaceutical calculations. Unfortunately, despite these expectations, errors do occur. A review of claims data from a national pharmacist professional liability insurance company found that 31.5% of claims related to compounding were attributable to calculation errors.² Even more alarming, an analysis of case reports entered into the Food and Drug Administration's Adverse Event Reporting System from 1993 to 1998 found that 13% of fatal medication errors resulted from dosage calculation errors.³

Recognizing the importance of performing pharmaceutical calculations with accuracy, the North American Pharmacist Licensure Examination (NAPLEX) blueprint contains 6 competency statements that specifically address pharmaceutical calculations.⁴ In addition, the Accreditation Council for Pharmacy Education (ACPE) includes dosage form preparation calculations in their list

of curricular topics critical to the foundation and delivery of effective patient care. Moreover, they recently included performing pharmaceutical calculations accurately as a core domain competency for students beginning their introductory pharmacy practice experiences and advanced pharmacy practice experiences.⁵

College students in the United States have deficiencies in their mathematical abilities.⁶⁻⁹ Data describing the incoming mathematics skills of pharmacy students is limited and largely from the United Kingdom.¹⁰⁻¹³ One study noted the incoming level of mathematics ability among pharmacy students significantly declined over a 7-year period.¹² A study of 121 students entering a private Southeastern US school of pharmacy reported the mean score on a basic mathematics skills test of only 68.9%.¹³ Only 2 studies were identified in the literature that evaluated pharmacy students' performance on a mathematics skills assessment before and after completing a pharmaceutical calculations course. Both of these studies were conducted in the United Kingdom and confirmed that overall student performance increased after completion of a pharmaceutical calculations course.^{10,12}

As of 2007, pharmaceutical calculations were taught as a standalone course in approximately half of colleges and schools of pharmacy in the United States.¹⁴ At the University of Cincinnati James L. Winkle College of Pharmacy, past PharmD students studied pharmaceutical calculations in a required, integrated fundamentals of

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pharmacy practice course during the first year (P1). Anecdotal evidence from the course instructor, however, indicated students were weak in their mathematics skills and a standalone basic pharmaceutical calculations course was warranted. Discussions with faculty members who taught later in the curriculum supported this belief. While the course was approved based on faculty perceptions, a systematic baseline assessment of students' pharmaceutical calculation abilities was not performed. Therefore, the primary objective for this study was to investigate changes in students' mathematics ability by content area before and after completing a required pharmaceutical calculations course. Secondary objectives were to examine the baseline mathematics skills of P1 students before taking a pharmaceutical calculations course, identify specific content areas of deficiency and excellence among the students, and compare scores between P1 students who completed the pharmaceutical calculations course and P1 students who did not take the course.

DESIGN

The 1-credit-hour pharmaceutical calculations course met for 50 minutes once weekly for 10 weeks. Classes were primarily lecture based with students completing calculation worksheets along with the instructor via use of an overhead projector. Course assessments included weekly homework assignments, 3 quizzes, and 2 examinations. Lecture topics and the placement of assessments for the course are listed in Table 1. Students were required to achieve an overall 90% average to receive a passing grade for the course. Students not achieving the 90% competency received an incomplete grade and were required to remediate within 2 quarters for their course grade to be released to the registrar. The pharmaceutical calculations course was the same for both cohorts.

A blueprint of content for a mathematics skills test was created based on ACPE Standards 2007 Appendix B, NAPLEX Area 2 competencies, the college's ability-based outcomes, information from chapters in several pharmacy calculation textbooks, and articles published on mathematics education in pharmacy.¹⁴⁻²⁰ Content areas included basic mathematics, calculating dosages, converting totals to percentages, the metric and apothecary systems of measurement, converting between units of measurement, calculating milliequivalents, utilizing mathematical ratios, determining flow rates for parenteral products, and extemporaneous compounding calculations. Test questions were categorized as either fundamental or application based. Fundamental questions required only a single step to solve, whereas application-based questions were word problems that required multiple steps to solve. A 37-item short answer pretest was developed by the authors based on

Table 1. Course Lecture Topics and Assessments in a Required Pharmaceutical Calculations Course

Week 1	Lecture: Course orientation, rounding, trailing zeros, proportions, dimensional analysis, interpretation of prescriptions, roman numerals
Week 2	Lecture: Metric system conversions, international units, pharmaceutical measurement, aliquots
Quiz 1	
Week 3	Lecture: Ratios, percents, density, specific gravity
Week 4	Lecture: Dosage calculations
Examination 1	
Week 5	Lecture: Dilution, concentration, alligation
Week 6	Lecture: Milliequivalents, milliosmoles
Quiz 2	
Week 7	Lecture: Calculations in extemporaneous compounding
Examination 2	
Week 8	Lecture: IV drug therapy: reconstituting powders, infusions, flow rates
Week 9	Lecture: IV drug therapy: admixtures, military time
Week 10	Lecture: Introduction to drug delivery/pharmacokinetics calculations
Quiz 3	

the blueprint. ACPE was just one of the resources used to prepare the blueprint for the math skills assessment. (The pretest is available upon request from the corresponding author). Thirteen questions were fundamental and 24 were application based. An emphasis was placed on application-based questions because students were expected to be able to apply the content in practice. The dosage and conversion calculation categories received more questions than the other categories because of the larger variety of category content (eg, dosage calculations include weight-based dosing, determining quantity to dispense, calculating day supply, etc). The posttest consisted of the same questions with different numerical values substituted.

EVALUATION AND ASSESSMENT

The pretest was administered to P1 students (class of 2013 [cohort 1]) prior to the pharmaceutical calculations course. They were allowed to use a 4-function calculator and were given 50 minutes to complete the examination.

Students were provided lunch as an incentive to stay after a required course and take the assessment. The posttest was administered to the same students 2 weeks after completion of the course. The posttest was administered after a required class period and 3 bonus points were provided on a pharmacy jurisprudence course examination (also taught by the corresponding author) as an incentive.

The same pretest used to assess cohort 1 was administered to P1 students (class of 2014 [cohort 2]) the following year with similar testing conditions (eg, test duration, calculator use). The same posttest used to assess cohort 1 was administered to the second cohort 6 months after completion of the course. The increased time between course completion and posttest administration was done to assess students' retention of the information.

Microsoft Excel was used for data entry. Statistical analysis was performed using SPSS 18. Paired *t* tests were used to compare differences in pre- and posttest scores. A *P* value <0.05 was considered significant. This study was exempt from Institutional Review Board approval as part of the college's programmatic assessment.

Of the class of 2013 (cohort 1), 96 students were enrolled in the pharmaceutical calculations course. Eighty-eight (91.7%) students completed both the pretest and posttest and were included in the study analysis. The students scored 13% higher on the posttest than on the pretest (Table 2). The number of students achieving a passing score (> 70%) increased from 38 to 77. Although 90 students met the competency requirement for the course, only 4 scored >90% on the posttest. No students scored >90% on the pretest. The lowest pretest score was 29.7 % compared to 51.4 % on the posttest. Approximately 80% of students' scores on the posttest increased compared with the pretest.

Eight students from cohort 1 were out of phase from their classmates because of previous course failures and were not enrolled in the pharmaceutical calculations course. These students took the posttest only. The mean score on the posttest was 58.1% ± 11.7%, with a high and low score of 73% and 37.8%, respectively. The students who completed the pharmaceutical calculations course scored significantly higher on the posttest than the out-of-phase students.

Of the class of 2014 (cohort 2), 98 students were enrolled in the pharmaceutical calculations course. Eighty-four students (85.7%) took both the pretest and posttest

and were included in the study analysis. The students scored 15.9% higher on the posttest than on the pretest (Table 2). The number of students achieving a passing score (>70 %) increased from 36 on the pretest to 79 on the posttest. Although 97 students met the competency requirement for the course, only 12 scored >90 % on the posttest. Two students scored >90% on the pretest. The lowest pretest score was 32.4% compared to 48.6% on the posttest. Approximately 89% of students' scores on the posttest increased compared with the pretest.

Students in both cohorts scored significantly higher on both fundamental and application-based calculations on the posttest (Table 3). The largest improvement was on application-based calculations in cohort 2.

Students in cohort 1 scored significantly higher in 6 of the 10 content areas on the posttest (Table 4). The largest improvement was in their ability to perform compounding calculations (34.4%), followed by milliequivalent (31.8%) and conversion calculations (25.3%). The mean score for ratio and apothecary calculations was the same for the pretest and posttest. The students scored lower in percentage (-2.3%) and significantly lower in basic mathematics (-8%) calculations on the posttest.

Students in cohort 2 scored significantly higher on the posttest in 6 of the 10 content areas. The largest improvement was in their ability to perform conversion calculations (31.5%), followed by compounding (26.2%) and flow rate (20.2%) calculations. As in cohort 1, the students scored lower in percentage calculations (-2.4%) on the posttest; this difference did not reach significance.

DISCUSSION

The results of this study support the inclusion of a required, standalone basic pharmaceutical calculations course in the college's curriculum. An improvement on posttest performance was observed among both cohorts following completion of the course. Also, the out-of-phase students in cohort 1 scored significantly lower on the posttest than their classmates who completed the required pharmaceutical calculations course. These students studied pharmaceutical calculations in the previously required, integrated fundamentals of pharmacy practice course. However, more time elapsed between when the out-of-phase students completed that course and when they took the posttest; thus, retention may have been a confounding factor.

Table 2. Scores on a Mathematics Skills Assessment Before and After Completing a Required Pharmaceutical Calculations Course

Cohort	No.	Pretest % Correct, Mean (SD)	Posttest % Correct, Mean (SD)	<i>P</i>
Cohort 1 (Class of 2013)	88	65.5 (14)	78.5 (8.5)	<0.001
Cohort 2 (Class of 2014)	84	66.5 (13.5)	82.4 (8.5)	<0.001

Table 3. Cohort Performance by Question Category on a Mathematics Skills Assessment

Category	No. of Questions	Cohort 1 (n=88)			Cohort 2 (n=84)		
		Pretest Correct, Mean %	Posttest Correct, Mean %	P	Pretest Correct, Mean %	Posttest Correct, Mean %	P
Fundamental	13	70.5	80.8	<0.001	70.3	83.2	<0.001
Application-based	24	62.8	77.3	<0.001	64.5	81.9	<0.001

To the authors' knowledge, this is the first study to assess United States pharmacy students' mathematics ability by content area before and after a required pharmaceutical calculations course. Mathematics skills assessments have been used to assess ability by content area among other health professions.^{9,12,21} McQueen and colleagues reported that medical students had the most difficulty performing percentage and infusion rate calculations, and Bayne and Bindler reported that practicing nurses had the most difficulty performing calculations that required multiple steps or required a conversion factor that was not provided.^{21,22} Students in this study improved in all of the above content areas following the required pharmaceutical calculations course, with the exception of percentages. Based on these findings, more emphasis should be placed on percentage calculations in our pharmaceutical calculations course.

Surprisingly, students in cohort 1 scored significantly lower in basic mathematics on the posttest. This is not encouraging and was not observed among cohort 2. The basic mathematics category only consisted of 2 questions. Because the focus of the course was pharmaceutical calculations, a review of basic mathematics was not provided.

McQueen and colleagues reported that mathematics skills were highly variable among medical students in the United Kingdom.²¹ Also, students' math ability at the time of matriculation varied greatly. Following the required

pharmaceutical calculations course, student mathematics abilities were more aligned as evidenced by the smaller standard deviations on the posttest among both cohorts of students. Requiring a pharmaceutical calculations course early in the PharmD curriculum may lessen the disparities in students' incoming mathematics ability.

Despite the expectation that students achieve 90% competency to pass the course, mean scores on the posttest were considerably lower than this. There are several possible reasons. The apothecary system of measurement was not taught in the course, and 1 question on this topic was included on the pretest and posttest. As expected, students performed poorly in this content area. The assessment was low stakes and students were not provided with an incentive for doing well, which may have impacted performance. Also, students were given the opportunity to achieve nominal bonus points in the pharmaceutical calculations course, which resulted in more students achieving 90% competency.

Students of cohort 2 retained their ability to perform pharmaceutical calculations for 6 months following the course. Information regarding the retention of pharmaceutical calculation ability among pharmacy students is limited. Brown and colleagues reported that 16% of surveyed colleges and schools of pharmacy formally measure calculations material retention via use of an annual comprehensive assessment; however, the authors did not find any such assessment data in the literature.¹⁴ One

Table 4. Cohort Performance by Question Content Area on a Mathematics Skills Assessment

Content Area	No. of Questions	Cohort 1 (n=88)			Cohort 2 (n=84)		
		Pretest Correct, Mean %	Posttest Correct, Mean %	P	Pretest Correct, Mean %	Posttest Correct, Mean %	P
Dosage	8	73.3	88.8	<0.001	71.6	91.4	<0.001
Conversion	7	62.2	87.5	<0.001	55.6	87.1	<0.001
Flow rates	4	63.9	76.1	<0.001	62.8	83	<0.001
Metric system	4	79.5	90.3	<0.001	82.7	93.8	<0.001
Percentage	4	86.4	84.1	0.38	93.2	90.8	0.132
Compounding calculations	3	47	81.4	<0.001	53.6	79.8	<0.001
Ratio	3	55.3	55.3	1.0	71.4	83.7	0.012
Basic math	2	87.5	79.5	0.008	75	76.8	0.75
Apothecary system	1	0	0	1.0	3.6	7.1	0.16
Milliequivalents	1	0	31.8	<0.001	16.7	20.2	0.64

pharmacy college reported that consistent repetition and assessment of mathematics skills throughout the curriculum was identified by its faculty as a “top 5” priority for curricular improvement.²³ Further studies should be performed to assess long-term retention of pharmaceutical calculation performance ability among pharmacy students.

This study has limitations. The mathematics skills test used was not a validated assessment instrument. Several content areas only had 1-3 representative questions, which may not have provided a thorough enough assessment of student ability in that particular content area. Also, the selected content areas did not encompass the full scope of pharmaceutical calculations in practice. For example, milliosmoles were taught in the course but not assessed on the mathematics skills test. Another limitation is that not all students in each cohort completed both the pretest and posttest.

This study also does not address the key question of whether improvements in mathematics skills lead to less calculation errors in practice. Theoretically, pharmaceutical calculation knowledge gained in pharmacy school will transfer to pharmacy practice; however, further studies should be performed in this area.

CONCLUSION

A required pharmaceutical calculations course improved PharmD students’ ability to perform both fundamental and application-based calculations. These improvements persisted for at least 6 months following the course. Further studies should be performed to address whether improvements in pharmaceutical calculation ability persist long term and whether completion of pharmaceutical calculation courses lead to less errors in practice.

ACKNOWLEDGMENTS

The authors thank Jared Timmons for his contributions to the data collection for this manuscript and the students who participated in the assessments.

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