

A constructivist method for teaching concentration calculations to pharmacy students

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Abstract

Concentration calculations are recognised as a general weakness in pharmacy undergraduate students, yet this is a crucial skill for a practising pharmacist. A constructivist environment encourages students to use their prior knowledge for better understanding of theories including mathematical concepts. This study compares the use of a constructivist environment to teach concentration calculations to a traditional, lecture-based course. The constructivist method used team work to develop competence and understanding of a series of relevant questions and measured individual and group understanding. Student competence following this constructivist course was similar to competence following a traditional lecture-based course. However, students indicated that they preferred learning within the constructivist environment compared to traditional lectures.

Keywords: *Concentration, constructivism, converting units, mathematics, medication errors*

Introduction

Concentration calculations, those involving expression of concentrations in a variety of ways has been identified as a weakness amongst nursing students and doctors (Kapborg, 1994; Rolfe & Harper, 1995; Lesar, Briceland, & Stein, 1997; Hutton, 1998; Weeks, Lyne, & Torrance, 2000; Kelly & Glaspole, 2006). No study has examined the competence of pharmacy students in such calculations although general mathematical ability has been identified as a common weakness in pharmacy undergraduates (Batchelor, 2004; Taylor, Bates, & Harding, 2004). This paper describes the use of a constructivist method to teach concentration calculations to first year undergraduate pharmacy students.

A miscalculation of medication dosage or incorrect conversion of concentration units represents a potential threat to both patient safety and clinical effectiveness. However, there is literature evidence that medication errors that include medication dosage and calculation errors are made in clinical practice (Leape et al., 1995; Lesar et al., 1997; Phillips,

Christenfeld, & Glynn, 1998; Runciman, Roughhead, Semple, & Adams, 2003). The term medication error has been defined in many ways, the National Patient Safety Agency (NPSA) has adopted the terminology of the US National Coordinating Council for Medication Error Reporting and Prevention:

“A **medication error** is any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of health professional, patient or consumer.”

Such errors may be related to professional practice, products, procedures, environment or systems. They may involve prescribing and ordering; dispensing and distribution; preparation and administration; labelling, packaging and nomenclature; communications and education; or use and monitoring of treatment.

Phillips et al. (1998) estimated that, in the US 7000 deaths each year are caused by medication errors, the same study stated that the number of deaths attributed to medication errors increased 2.57-fold from 2876 in 1983 to 7391 in 1993. The Adverse Drug Event Prevention Study Group in the US reported that

harmful medication errors occurred in 1.8% of hospital admissions (Leape et al., 1995). A more recent Australian study showed that about 1% of all hospital admissions suffered an adverse event as a result of a medication error (Runciman et al., 2003). Because of low reporting rates the incidence of medication errors within the NHS is not known. The National Patient Safety Agency has been set-up to collect, collate, review and analyse error reports and produce and disseminate solutions to reduce risk, the recent report, "Building a safer NHS for patients: Improving Medication Safety" (Smith, 2004), will address this in future. According to this report by Smith (2004), medication errors are consistently reported to account for between 10 and 20% of all adverse events, with the direct cost of medication errors in NHS hospitals estimated to be £200–400 million/year.

However, it is difficult to determine the proportion of medication errors that relate to dosage calculations as most medicines are available in formulations that correspond to their usual dose. Nonetheless, these calculations do need to be performed, particularly for some potent medicines prescribed for adults and many medicines for children; in these instances the dose, volume or rate of administration needs to be calculated. These calculations can prove difficult and may be a source of error. In an American study of medication prescribing errors, the overall rates of errors was 3.99 errors per 1000 medications and of these 11.1% were attributed to incorrect dosage calculations (Lesar et al., 1997). Rolfe and Harper (1995) investigated the ability of hospital doctors to convert between mass concentrations, dilutions, and percentage concentrations; around half the doctors surveyed were unable to convert drug doses correctly from a percentage concentration or dilution to the more conventional mass concentration and only 28% felt they had been given adequate training in this area.

In 2003, the General Medical Council of the UK made recommendations on undergraduate medical education that specify that students should be able to "work out drug-dosage and record the outcome accurately" (GMC, 2003). There have also been reports on difficulties that nurses face with calculation questions, in a study by Ashby (1997) of medical-surgical nurses more than half could not correctly solve 90% of the problems on a calculation examination. There are limited reports of pharmacists and dosage calculation errors; although amongst pharmacy undergraduates it is recognised as a general weakness. In fact, the Moser report (1999) suggested that as many as 40% of the adult UK population have some numeracy problems. On the positive side it has been reported that pharmacist intervention has reduced medication errors (Folli, Poole, Benitz, & Russo, 1987; Blum, Abel, Urbanski, & Pierce, 1988; Fortescue et al., 2003), this intervention relies on the

fact that the pharmacist can recognise and correct errors that may have been made.

The traditional method to teach calculations is formula-driven; that is, an example is presented with a formula that describes how the calculation was performed (see Figures 4 and 5 for typical examples). This is widely used in pharmacy with many books devoted to such methods (for example, *Introduction to Pharmaceutical Calculations* by Rees Smith, & Smith, 2001). Students are then able to practise using the given formula hoping to develop competence. Many students can perform well if the calculation is presented in the same way as the original example yet find the explanation or any deviation from this standard far more difficult. Typically the problem is divided into simple steps that are worked through using "mimetic activity" to demonstrate to students what is required.

However, this traditional approach may not be consistent with students' information processing styles which, in turn, can hamper their learning (Gredler, 2001). Another obvious disadvantage is that students may follow the steps correctly and arrive at the desired solution yet not understand the underlying process or underlying concept behind the solution. A greater worry is that students that get the correct answer believe that they understand the concept, yet may perform poorly in an examination or an alternative learning environment where the problem arises in a different context. Instead of gaining a deep conceptual understanding students are likely to merely imitate the procedures to acquire the desired results. In teaching these calculations to students it is common to break it down into what we (the teacher) believes to be a series of simple steps based on our data processing skills. If our processing patterns match those of students then this is a successful strategy although if not this can be very limiting.

Within nursing there have been two major reports on the quantitative skills that nurses actually need (Pirie, 1987, Hilton, 1999); such a report would be extremely useful for pharmacists.

The following is a suggestion of quantitative skills that are required for pharmacists, in relation to converting concentration terms, as adapted from Hilton's list for nurses:

- multiplication involving two digit numbers,
- division of an integer by a number between one and nine,
- multiplication of two decimal numbers,
- multiplication of two fractions,
- division of two fractions,
- conversion of fractions to decimals,
- conversion of decimals to percentages,
- calculating percentages of integers,
- conversion between SI units, and
- multiplication of integers and decimals by 10, 100 and 1000.

Such a list of competencies is desirable as it provides a focus for teaching and also offers many opportunities to contextualise the mathematics so that students can see the relevance and importance of these skills for their future career.

In contrast with traditional classroom-based techniques, the constructivist environment provides students with opportunities to develop their abilities to adapt and change methods to fit new situations. This aspect of mathematics relies on the students' ability to perform addition, subtraction, division and multiplication yet the student needs to understand the problem to work out which of these functions is required at each step.

Constructivists believe learners bring individual past experiences, ways of thinking and motivations to any learning activity. These learner characteristics influence how knowledge is constructed and perceived (Greeno & Hall, 1997). Paramount to this approach is the value placed on student thinking (Brooks & Brooks, 1993). Rather than focus on the "right answer" students are encouraged to think through the process of problem solving as instructors ask students to describe their methods of arriving at a solution, as well as to justify that their answer makes conceptual sense.

The instructor's role in this method is to provide situations that can be solved in a variety of ways, engage all students within the class and probe students' thinking as they discuss solution strategies. The goal is that students develop strategies that best suit their individual information processing. The instructor is there to aid students in producing an answer that is not only correct but also makes sense to the students.

The essence of constructivism has been summed up by Shuell (1996):

"What the student does is actually more important in determining what is learnt than what the teacher does".

This method requires small student groups where students contribute to a large extent to the discussion.

Constructivism is a theory about how learners come to know, it is not an educational approach although this paper demonstrates a study where this theory was put into practice. The key points are that instructors must never do students learning for them, rather the instructor should facilitate the process within each student as the knowledge exists within the context of the learner and meaningful learning is unique to each individual student. A constructivist learning environment is defined as a place where learners may work together and support each other as they use variety of tools and information resources in their guided pursuit of learning goals and problem-solving activities (Wilson, 1996).

Constructivist methods have been used in nursing education to aid conceptual understanding of medical calculations (Kelly & Colby, 2003). Weeks et al. (2000) used a computer-based constructivist approach to teaching medication dosage calculations to nurses; he found that the constructivist approach provided a better framework for mathematical learning. In addition to the constructivist environment, much emphasis has been placed on using visual aids to reinforce mathematical principles. This is also linked to the constructivist theory of learning. The use of visuals linked into calculations has produced promising results in nurses' calculation performance (Weeks et al., 2000). Wheeler et al. (2006) used an online tool to aid doctors' learning about drug dosages that included images in the question set; this proved successful although interestingly not all students chose to participate.

This study evaluates a constructivist environment to teach dosage calculations to pharmacy undergraduate students. Evaluation of constructivist teaching is complex as the principle behind this teaching strategy is to fix concepts, procedures and methods into students' minds rather than focussing on getting the correct answer. However, constructivism has been broken down into the five "E's": engage, explore, explain, elaborate and evaluate (Miami Museum of Science, 2001). Within this study the engagement aspect was performed by demonstrating to students the importance of this knowledge in relation to both their studies and their future careers. Students were asked to explore these concepts both as individuals and then to come together in a team to explain and elaborate on the work they had done and the procedures they had used to arrive at the answer. A questionnaire, based on the learning experience aimed to address these five E's to determine the students' experience of these parameters. Students were presented with a series of statements, that mapped onto the five E's and were requested to circle a response from "Strongly agree" through to "Weakly agree" for each statement. The list below shows how some of the statements map onto the five E's:

- Engage: I see the relevance of this work for my future career
- Explore: I found it useful to discuss these problems with my colleagues
- Explain: I enjoyed collaborating with others in this work
- Elaborate: Sometimes other students can explain ideas better than a lecturer
- Evaluate: I learnt some useful tips within this session

I think that my competence in this type of calculation has improved

First year undergraduate pharmacy students at Aston University have traditionally been taught mathematics within a standard lecture format with access to additional similar problems and answers either within textbooks or, more recently via a virtual learning centre. In addition, quizzes have been available online for students to practice routine calculations, however, a previous study documented that these tests were generally poorly utilised (Batchelor, 2004). Within pharmacy particular emphasis is placed, necessarily, on the mathematics involved in calculating concentrations and converting between different units of concentration.

As this is the most obvious and important mathematics involved in pharmacy it was decided that this subject would be appropriate to use to develop a constructivist classroom. This topic has an obvious applicability in the future career of the students and thus the importance placed on this topic is high. This study describes a constructivist approach to teaching concentration calculations to pharmacy students and the evaluation of this approach both in terms of providing a constructivist environment and also aiding learning.

Methods

Typical problems involving concentration calculations that may face a practising pharmacist were used in the session. The session was divided into four tasks:

- *Task one:* students had 1 week to work on a set of 32 problems on concentration conversions. They were encouraged to work alone, yet refer to any material that they found useful and not to worry if they could not complete the full set of questions. Staff were requested not to assist students at this stage. Tasks two, three and four took place within a timetabled 3-hour workshop
- *Task two:* students formed teams within a timetabled session to discuss the question set and to complete a team answer sheet of an identical set of the 32 questions.
- *Task three:* students remained within their teams and were presented with eight similar questions that they had to complete within 45 min, they were requested to show their workings and submit a team response
- *Task four:* students were presented with a further four similar questions that were completed as individuals, they had 40 min to complete these questions.

Calculators were permitted at all stages.

The students were allowed to select their own team with a maximum of eight members. The assessment was based not only on individual performance but also on the performance of the team.

Within Task two academic staff and postgraduate demonstrators were available to advise the student teams if they requested assistance. Students were asked to note if they all got the same answer to the problem set; where differences occurred students were asked to work through the problems to see which answer the team felt was correct. If the team could not agree they were assisted by a member of staff and directed towards the correct answer. However, the correct answers were only provided upon submission of the question set, ensuring that students received immediate feedback and had the opportunity to discuss these errors as a team, and also with a member of staff, prior to the next task.

Within Tasks two and three the group were encouraged to share the methods that they used to solve the problem and to assist those students that could not solve the problem. During the session it was anticipated that many of the students would use traditional formulae to solve the problems yet they would express these in a way that made sense to them.

This workshop was assessed using both individual and team performance, students were made aware of the assessment strategy prior to the session and were advised that effective team-working was advantageous. The basis of constructivism is that students share their methodology to aid in learning, so by sharing techniques the weaker members of the team may be better able to solve the calculations thus improving the overall team result.

Assessment scheme

- 25% of the marks were awarded for the team sheet that was identical to the original 32 questions, submitted during the session (Task two)
- 25% of the marks were from the eight example problems that were submitted by the team during the session (Task three)
- 25% of the marks were from the individual response to the four questions that were submitted (Task four)
- the final 25% of the marks were calculated using the mean score of the individuals in each team for the four problems that the individuals completed.

Evaluation of the efficacy of the constructivist classroom was via a questionnaire distributed to students for immediate feedback. The questionnaire was distributed to students to discover their thoughts on the constructivist method as a strategy to learn concentrations; this was based on the five E's used to measure constructivist learning environments. The statements in Table I were provided with the option to; strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree and strongly disagree.

Table I. Evaluation statements used to measure the success of the constructivist classroom, the percentage of responses that were agree or strongly agree are shown ($n = 147$).

Statement:	Percentage of students that strongly agree and somewhat agree (%)
I enjoyed this session on concentrations	63.1
I found it useful to discuss these problems with my colleagues	76.5
Sometimes other students can explain ideas better than a lecturer	66.4
I enjoyed collaborating with others in this work	77.2
I liked working as part of a team	78.5
I think that my competence in this type of calculation has improved	63.1
I would prefer to be taught these methods within a lecture	53.0
I learnt some useful tips within this session	59.7
I see the relevance of this work for my future career	73.8
I enjoyed the teamwork aspect of the assessment	69.8
I think that the assessment technique for this session is fair	53.7

The timetabled sessions for the constructivist classroom were scheduled within the first month of the students' university education and a follow-up questionnaire administered at the end of term one revisited this session for some long-term reflective views. Students were requested to compare the constructivist learning to a lecture series on additional mathematics via the following question;

Compare how you enjoyed the lectures compared to the concentrations workshop (experiment one) that you did in weeks two/three of this term. This was the set of questions that you did alone and in teams.

Please circle the answer that applies most:

I learnt more in the:

Concentrations Workshop Lecture

I enjoyed learning in the:

Concentrations Workshop Lecture

Results and discussion

The constructivist session was run twice for the first year pharmacy undergraduate cohort, each time with half the year group (approximately 70 students in each session). It was hoped that this could be run four times, thus reducing the overall cohort but timetabling restricted this. In each session the largest team was eight members and the smallest four with the most teams comprising six members.

In total there were 24 teams; in Task two, six teams scored full marks, most other teams scored above 29/32 with four teams scoring between 22 and 27 out of 32. This result was very promising as it demonstrated that the questions were appropriate for the student group and that in groups the students were confident and generally able to answer the questions. The one group that scored 22/32 had not previously attempted the questions that they had been given, which probably explains this poor result. In some groups this appeared to be an issue with some members having prepared for the session and others not having attempted the question sheet. It is difficult

to overcome this as the importance of the work had been clearly emphasized to the students and they were allowed to select their own group members and vary the size of the group so that they could work with like-minded individuals. As the individual mark awarded depends to a large extent on the performance of the team the students did tend to work in groups where they had all completed at least some of the problems.

Figure 1 shows that the scores for the initial 32 questions were somewhat related to the team score in the next set of eight questions, in that the team that was weak initially scored the lowest mark in the additional eight questions and all the teams that scored full marks in the initial 32 questions also scored highly, either seven or eight out of eight in the next set of questions (Task three).

Task four assessed individual ability in a further four similar questions. Figure 2 shows the average team score out of four (Task four) compared to the team score in the initial 32 questions (Task two) and in the additional eight questions (Task three).

Four students scored less than one (out of four) in Task four yet more than two thirds scored three or above. This result was promising in that most students were scoring above 75% in these calculations following only a 3-hour taught session.

Students undertake a diagnostic test at the very start of the term (prior to this session), one question on this test involves a simple concentration conversion. Following the lecture course a mid-session test also

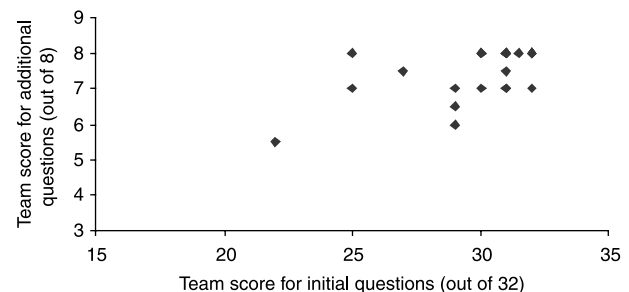


Figure 1. Comparison of the team scores for Task two (x -axis) and Task three (y -axis).

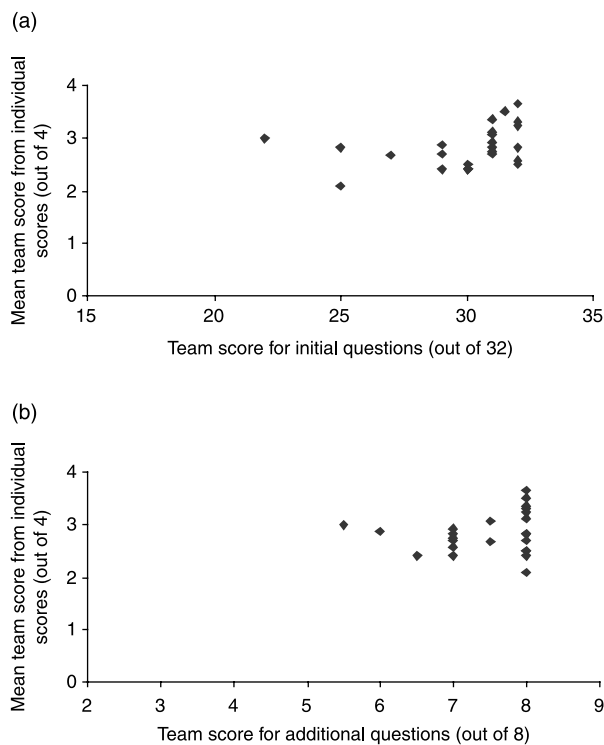


Figure 2. (a) Comparison of the mean team score for Task four (y -axis) and the team score for Task two (x -axis). (b) Comparison of the mean team score for Task four (y -axis) and the team score for Task three (x -axis).

asks a simple concentration calculation, as shown in Figure 3 and this can be used to determine what has been learnt during the lecture course. The results of this comparison are compared for the current cohort who were taught using a constructivist method and compared to the results for previous year who were taught using conventional lectures.

Sixty-four percent of the current cohort initially gave the correct answer to this question within the diagnostic test whereas after the course 96.0% got a similar question correct following teaching via the constructivist method. Last year, 65.0% got this correct initially and 91.3% got a similar question correct following a traditional lecture course. This result shows that students can learn via both methods

and can perform this type of calculation following instruction.

This study aimed to use a constructivist environment to enable students to develop their own methodology to answer questions relating to concentration conversions. They were provided with an opportunity to work alone and with others to develop methodologies and they were able to use whatever resources, including textbooks or websites that aided in developing these skills. Conventional methodology, suggested in most Pharmaceutical Calculations textbooks suggests that certain questions are tackled following a rigid structure as shown in Figures 4 and 5.

Although approximately half the students did use this method in answering a similar question within Task three, others simplified it and did not feel the need to write the full ratio equation and rearrange.

No students used this long version to perform the calculation yet all teams got this correct in Task three. Much shorter versions of this calculation were used.

These two examples highlight the overall findings that students find a simpler way to represent their calculations in a way that makes better sense to them as individuals based on their prior learning. In providing the full answer and methodology to certain students, it may actually hamper their learning as they are confused by the methodology yet not confident in their own methods to calculate the answer.

Feedback of the efficacy of the session is drawn from the questionnaire with results shown as the percentage of students that agreed somewhat or strongly with the statements provided in Table I.

It is encouraging that the students both enjoyed this session and found it useful.

The success of this session was evaluated according to the five E's within constructivism; the questionnaire was used to measure whether the session had tackled the five E's. Taken in order, this exercise aimed to engage students by making it relevant to their career; over 70% of students could see the relevance of this exercise in terms of their career. Exploration was measured by discussion of the topic with colleagues. Table I shows that over three quarters of students found discussion with colleagues useful to explore

If the concentration of drug is 2.5 % m/v how many grams of drug would be present in 60 mL?

A. 2.5 g

B. 1.5 g

C. 4.2 g

D. 15 g

E. 150 g

Figure 3. A typical question format used in both the diagnostic or midsessional test.

Question:
Concentrated drug solution is available as a 60 mg/mL solution. The patient requires a dose of 27 mg, what volume should be administered?

Standard calculations textbooks (Rees et al 2001) suggest using ratios to perform these calculations such that:

Drug (mg)	60	27
Product (mL)	1	r

To determine the volume required, student are suggested to use a method of ratios:

$$\frac{60}{1} = \frac{27}{r} \quad \text{So, } r = \frac{27}{60} \times 1 = 0.45 \text{ mL}$$

Figure 4. Suggested methodology to perform the calculation presented, adapted from a method shown in Rees et al., 2001.

ideas. The explanation aspect was measured by using the question about collaborating with colleagues and again this received a very positive response. Elaboration was difficult to measure directly but it was based on the question that students explaining material is equivalent to a student elaborating on material. Sixty-six percent of students felt that students can sometimes explain things better than a lecturer. Finally, evaluation was measured to assess how students feel

their ability in this area has improved; 63% felt that their competence has improved and 60% felt that they had learnt some useful tips within the session.

These results demonstrate that this session addressed the five E's believe to be necessary in a constructivist environment and on the whole they were met by the majority of the students. One limitation was that the questionnaire was administered directly following the timetabled session and students

Question:
What weight of ingredient is required to produce 200 mL of a solution such that when 10 mL of it is diluted to 120 mL with water it gives a 0.3 % w/v solution?

The recommended method is to look at the final solution where there is both a mass and a concentration:
By convention 0.3 % w/v means 0.3 g in 100 mL

Mass (g)	0.3	m
Volume (mL)	100	120

Where m is the mass of drug in 120 mL

According to the ratios; $m = \frac{0.3}{100} * 120 = 0.36 \text{ g}$

This mass must have been present in the 10 mL aliquot taken:

Mass (g)	0.36	m_2
Volume (mL)	10	200

Where m_2 is the mass of drug in 200 mL

According to the ratios; $m_2 = \frac{0.36}{10} * 200 = 7.2 \text{ g}$

Figure 5. Suggested methodology to perform the calculation presented, adapted from a method shown in Rees et al., 2001.

had not had time to fully reflect on their experience. The follow-up question that asked students to compare the constructivist classroom to a lecture series found that there was a relatively even split in the students as to where they felt they learnt more, with 54.7% responding that they learnt more in the concentrations workshop and 45.3% felt they learnt more in the lectures. However, 73.4% preferred learning within the concentrations workshop compared to 26.6% within lectures.

As a lecturer this is an enjoyable way to teach relevant mathematics. Additional benefits involve the aspects of team-working and encouraging students to discuss their concerns with other to make the best use of their colleagues to aid their learning. The enjoyment from this type of learning may be as much to do with the novelty of a constructivist environment compared to a lecture theatre as to the strategy employed, however, by exposing student to a range of learning and teaching environments they can make a judgement on how they want to further manage aspects of their own learning. A follow-up study is planned to note the long term effects of constructivist learning of this aspect of mathematics.

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