Safety in numbers 2: Competency modelling and diagnostic error assessment in medication dosage calculation problem-solving

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A B S T R A C T

Accurately defining and modelling competence in medication dosage calculation problem-solving (MDC-PS) is a fundamental prerequisite to measuring competence, diagnosing errors and determining the necessary design and content of professional education programmes. In this paper we advance an MDC-PS competence model that illustrates the relationship between conceptual competence (dosage problem-understanding), calculation competence (dosage-computation) and technical measurement competence (dosage-measurement). To facilitate bridging of the theory—practice gap it is critical that such models are operationalised within a wider education framework that supports the learning, assessment and synthesis of cognitive competence (the knowing that and knowing why of MDC-PS) and functional competence (the know-how and skills associated with the professional practice of MDC-PS in clinical settings).

Within the context of supporting the learning and diagnostic assessment of MDC-PS we explore PhD fieldwork that challenges the value of pedagogical approaches that focus solely on abstract information, that isolate the process of knowledge construction from its application in practice settings and contribute to the generation of conceptual errors. We consider misconceptions theory and the concept of mathematical ‘dropped stitches’ and offer an assessment model and program designed to diagnose flawed arithmetical operation and computation constructs.

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Introduction, background and aims

Past, present & future challenges in medication dosage calculation problem-solving (MDC-PS) education

When children are presented with information that is divorced from their experience, they strive to connect it with the most approximate reality with which they are familiar. Eric Midwinter gives a memorable example of this,

"Some time ago I inspected a child’s drawing of ‘Silent night; Holy night’. As well as the traditional complement of holy family, wise men, shepherds, oxen and asses, there was also a cheerful, stout fellow in a brown jerkin gazing benignly into the crib. ‘Who is that?” we asked… ‘Round John Virgin’, said the artist.

Excerpt from ‘The Irrelevance of the Curriculum’ (Midwinter, 1972, p. 278).

Some people who read this extract immediately understand the child’s misconception, while others ironically fail to ‘see’ the meaning in Midwinter’s description (‘see’ Fig. 1 for an artist’s impression to support the textual description). In this paper, we explore an analogous problem associated with nursing curricula that divorce the classroom from the real world of clinical nursing practice. We argue that such curricula perpetuate a theory—practice gap that negatively affects the learning of MDC-PS knowledge and skills. This gap is evident when nursing students fail to ‘see’ the meaning embedded in the language and symbols of medication dosage calculation word problems and/or the actions of registered practitioners performing dosage calculation problem-solving in the practice setting.

This theory—practice gap is significant because a failure to effectively learn MDC-PS knowledge and skills can contribute to medication errors in clinical nursing practice. Medication errors are
the most prevalent type of medical/nursing error recorded worldwide. Reported incidences of dosage calculation errors in clinical nursing practice average 5% of all errors, with reported rates of up to 14% (Dean et al., 1995; Lesar et al., 1997; Taxis and Barber, 2003). Rates of up to 33% have been cited for incorrect dose administration (Raykens and Larsen, 2010). In the UK, 25% of the UK National Health Service (NHS) litigation bill involves cases of drug error and the UK Department of Health (2000, 2004) has prioritised making the NHS safer for patients. A significant proportion of these errors have been blamed on inadequate staff training and assessment. The most common contributory factors are miscalculation, failure to titrate doses to patients’ needs, miscommunication and all team members failing to check doses before dispensing, preparing or administering medication (NPSA, 2009). Medication dosage calculation errors are highlighted as an aspect of clinical governance and as a key target for remedial action (Wright, 2006; Jukes and Gilchrist, 2006; NPSA, 2006a,b, 2009). In the light of these issues we wish to question the value of mechanistic and teacher-centric practices that have traditionally treated students as passive recipients of decontextualised and symbolic (word- and number-based) knowledge. We argue that these practices isolate the process of knowledge construction from its application in clinical practice, and perpetuate a theory–practice gap. In this paper we:

1. Explore competence in MDC-PS. We illustrate the design of a MDC-PS competence model that articulates the relationship between the conceptual, calculation and technical measurement facets of MDC-PS competence. It also allows for diagnosis of errors in these three competence domains.

2. Describe how the traditional classroom-based transmission models of education, as well as the proceduralisation of the medicines management process in clinical practice generate a theory–practice gap and contribute to MDC-PS conceptual errors.

3. Explore the origin of calculation errors and offer an assessment tool to assist diagnosis of errors in calculation that manifest as MDC-PS arithmetical operation and computation errors.

The ideas, analysis and frameworks described in this paper are a precursor to the other papers in the series that explore the development and evaluation of authentic environments that have been designed to bridge the theory–practice gap and develop nurses’ MDC-PS competence.

Methodology

In this paper we explore the problem assessment and framing phase of a 20-year programme of medication dosage calculation problem-solving (MDC-PS) education action research. In Weeks et al. (2013a) we explain the basis of the education action research process, and here we describe the fieldwork that preceded a PhD research programme undertaken at a large UK university. This work took place in the early years of the programme and describes the work with nursing students who had mostly been school educated in the late 1970s to early 1990s period.

The fieldwork investigated MDC-PS competence requirements and addressed university nursing students’ medication dosage calculation errors. It began with a five-year period of action research fieldwork punctuated with episodes of ethnographic study, elements of which have been reported in detail previously (Weeks, 2001; Weeks et al., 2000,2001; Lowes and Weeks, 2006). By gaining entry to the students’ world via an emic perspective (Pike, 1967), it explored and attempted to empathize with the way students perceived the teaching and learning methodologies used in classroom and clinical practice environments when they were learning dosage calculation problem-solving skills. Participant observation, field note recording and post-experience interviews took place during classroom-based theoretical preparation, and clinical placements where medication dosage calculation problem-solving formed a part of wider medicine and patient care management. Detailed student evaluations of these experiences are reported in Weeks et al. (2013d).

We begin our exploration of the problem assessment and framing process with an analysis of the design features of a MDC-PS competence model.

Defining competence in MDC-PS

Facilitating the construction of professional knowledge and its application to professional competence development, performance, assessment and evaluation is a key mission of professional healthcare education and lies at the heart of professional registration and maintaining patient safety in clinical practice. However, in nursing education we have traditionally made a distinction between the teaching and assessment of knowledge and the teaching and assessment of competent and skilled performance. Thus in a traditional education system we have created not only a theory–practice gap, but also a knowledge-performance gap that separates ‘knowing that’ from ‘knowing how’. This problem is exacerbated when we attempt to define and describe the requirements of competent performance through propositional language. Lum (2004) on questioning whether competence can be described and communicated via language in accurate and unequivocal terms, concluded that,

Ultimately, the essentially non-discursive nature of human capability can be seen to have important ramifications for both curriculum design and assessment in vocational education and training. It certainly raises serious doubts about the wisdom of an approach based on the assumption that it is possible to describe competence in precise detail. It would seem that in the last analysis present arrangements can only provide us with an impoverished and insufficient account of the educational enterprise and a mode of assessment which inevitably falls short of what it sets out to do (p. 496).

More recently Wright (2012) and Weeks et al. (2013b) have called for a review and rethink of both the traditional method for
describing competence and for developing authentic education environments to support the learning and assessment of MDC-PS. In this context, Fig. 2 illustrates a MDC-PS model which KW initially developed during the 1992–2001 phase of the education action research programme (Weeks et al., 2013a), and was further developed in collaboration with colleagues during an NHS Education for Scotland (NES)-commissioned programme of research (Weeks et al., 2000; Hutton et al., 2010; Coben et al., 2010; Sabin et al., 2013). The model in Fig. 2a reflects definitions of the three sub-elements of the competence model; and Fig. 2b reflects example iconic representations of the word-based definitions. This highlights the difficulty noted by Lum (2004, 2009) in accurately describing competence in precise detail in a word-based form and this phenomenon is fully explored here and by Weeks et al. (2013b).

The premise of this model was reported by the UK Nursing and Midwifery Council (NMC) in its ‘Supporting Advice to the new Pre-Registration Standards’ (NMC, 2010b, p. 60–61). It articulates the inter-relationship between the three sub-elements that combine to form competence in medication dosage calculation problem-solving. The confluence (central white section) of the model highlights how all three sub-elements must be practised concomitantly in order to achieve a correct dosage or rate solution. The model outlines:

1. **Conceptual competence – the need to:**
   a) Understand the elements of prescription charts, dispensed medication labels and medication data sheets and monographs, and to subsequently extract the numerical information necessary to set up the dosage problem correctly.
   b) Position the numerical information appropriately and correctly in an equation format for calculation.

2. **Calculation competence – the need to:**
   Correctly apply arithmetical operations and compute an accurate numerical value within a safe and acceptable tolerance range for the prescribed medication dose, and/or rate of administration.

3. **Technical Measurement competence – the need to:**
   a) Select an appropriate medication administration measurement vehicle (tablet or capsule, oral liquid medicine measurement cup, syringe, infusion pump etc.).
   b) Accurately transform the calculated numerical value to the context of the measurement device/formulation and measure the correct dose of prescribed medication; and/or administer the correct rate of prescribed medication/IV infusion fluid.

If an uncorrected error is made within any one or more of the sub-elements of the competence model then a medication dosage calculation error in the practice setting will result.

**Cognitive and functional competence: a model for bridging the theory–practice gap**

Nursing and other healthcare professions possess a unique body of professional knowledge that informs and provides an evidence-based rationale for its clinical practice. The European Qualifications Framework for Lifelong Learning (EQF) has described the relationship between theory and practice in the form of four competence domains (European Communities, 2005, p. 4):

- **Cognitive competence** — the use of theory and concepts, as well as informal tacit knowledge gained experientially;
- **Functional competence** (skills or know-how) — those things that a person should be able to do when they are functioning in a given area of work, learning or social activity;
- **Personal competence** — knowing how to conduct oneself in a specific situation;
- **Ethical competence** — possessing certain personal and professional values.

The EQF subsequently defined the synthesis of these competence sub-domains as:

> The proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development (European Communities, 2008, p. 11).

This premise informs the model for MDC-PS competence development, integration and progression. However, Fig. 3 illustrates how in professional clinical practice functional competence, i.e., the observable ‘know-how and skills’ demonstrated by the competent registered practitioner, represents the observable tip of a competence iceberg that is underpinned by a very significant but commonly hidden cognitive, ethical and personal competence professional knowledge base.

We will explore how despite the excellent mentorship practices observed in practice settings, the sheer pace of healthcare delivery may limit students’ exposure to the expert knowledge and problem-solving processes that underpin practitioners’ demonstrated functional competence. This phenomenon when combined
with abstract classroom-based pedagogies that isolate the process of knowledge construction from its application in practice settings contributes to the generation of a theory–practice gap.

Throughout this series of papers we argue for the use of authentic virtual environments and other clinical simulation-based learning activities that actively engage learners in the construction of knowledge and externalize expert knowledge and problem-solving processes that support:

a. The construction and diagnostic assessment of cognitive competence in MDC-PS, i.e., the knowing that and why declarative/propositional knowledge that represents the understanding of conceptual, calculation and technical measurement features of MDC-PS and their relationship to each other;

b. The enculturation and sensitization of learners to the essential functional competence requirements of 21st century MDC-PS practice. These are the procedural MDC-PS know-how and skills that represent the outward articulation and demonstration of declarative/propositional knowledge and which must be demonstrated and assessed in clinical practice settings.

c. Bridging of the theory–practice gap.

We now explore our premise on the origin and diagnosis of MDC-PS errors that was derived from the 1992–2001 cycle of the education action research.

The origin, definition & diagnosis of MDC-PS errors

The classroom environment

Our classroom-focused fieldwork at the study site revealed that students were taught via traditional classroom-based ‘chalk and talk’ pedagogies using word-based dosage calculation problems, formulae and number-based equations via (see Fig. 4) and assessed via word-based problems of the type illustrated in Fig. 5.

Traditional classroom-based pedagogies attempt to transmit knowledge of the medication dosage calculation problem-solving (MDC-PS) process, yet these abstractions (words and numbers) are divorced from the real world of practice that they attempt to represent. They represent a weak and impoverished method of supporting students’ learning of these skills. To compound this problem, lecturers at the study site used variable terms to describe dosage calculation formulae and equations. We observed three variations that centred around:

a. What you want, over what you’ve got, times what it’s in.

b. Need over Have times Supply (NHS).

c. Prescribed dose over Dispensed dose times by Quantity the dispensed dose is contained in (PDQ).

Hutton (1998a) reported similar variations at another UK college of nursing, while Worrell and Hodson (1989) reported that in their study of 72 baccalaureate nursing programs in the USA, 48 equation variations were used in setting up the same dosage problem. Students need to understand the clinical source of and the relationship between the elements of dosage and rate formulae and equations if they are to conceptually understand, accurately set-up and solve dosage problems. Our fieldwork was to highlight how traditional classroom-based pedagogies and the interchangeable...
The nature of conceptual errors

The typical conceptual errors that were committed by pre-registration nursing students (undertaking nursing foundation studies) during written dosage calculation assessments involved misconceptions of the relationship between elements of word-based problems and formulae, and erroneous setting up of dosage calculation equations. This phenomenon has been reported elsewhere (Weeks, 2001; Weeks et al., 2001; Hutton et al., 2010) and is summarized here and illustrated with examples of typical conceptual errors (see Figs. 6 and 7).

Fig. 6 illustrates a misconception about the relationship between the three elements of the injection medication dosage calculation problem: the prescribed/ordered dose, the dispensed dose and the quantity (e.g., volume in milliliters etc.) in which the dispensed dose is contained. The correct solution is 2.5 mg/10 mg × 1 mL = 0.25 mL and illustrates an error if uncorrected of sixteen times the prescribed dose.

Fig. 7 illustrates a similar misconception about the relationship between the three elements of the oral liquid medicine dosage calculation problem. The correct solution is 1 mg/2 mg × 5 mL = 2.5 mL and illustrates an error if uncorrected of four times the prescribed dose.

The conceptual errors illustrated in Figs. 6 and 7 were produced following exposure to classroom-based didactic education illustrated in Fig. 4. Following the ethos of action research (inquiry founded on a partnership between researchers and participants who are collectively engaged in change: Stringer, 2008) we needed to engage in meaningful evaluative discussions with our students to effect a change within a domain with a 70-year protracted history of error.

Bernstein (1973, p. 85) describes how evaluation ‘defines what counts as a valid realization of the knowledge on the part of the taught.’ However from our experience, it is easy to miss what counts as a valid realization of knowledge from student evaluations. Many students evaluated their exposure to this type of classroom-based didactic transmission method with statements such as, “I couldn’t see what the lecturer was talking about” or, “I can’t see how you worked that out.” For many years these evaluations were largely interpreted as colloquialisms. However, on closer analysis it began to emerge that effective learning for many students involves the need to visualize or “see” the elements of a problem in a concrete or iconic (physical or picture) form, rather than solely reading or hearing such problems articulated in a symbolic (word and number) based form (Lowes and Weeks, 2006; Weeks et al., 2013d).

Moreover, in our study we observed that this problematic feature of traditional classroom-based pedagogy was compounded by clinical mentors commonly ‘proceduralising’ MDC-PS processes in clinical practice.

The clinical practice environment

During our five-year period of action research fieldwork we observed examples of excellent mentorship, where during quiet periods, registered nurses were observed to explain and illustrate their medication dosage calculation practices to nursing students. However Coben (2010) and Eraut (1994) highlight how given the increasing demands and pace of professional practice, professionals also commonly learn to use routinised practices. Experienced nursing staff who have embedded computation within their practice may no longer recognise the presence of calculation in routine care (Hutton, 1998a). In our study, this was exemplified during busy periods when there was pressure to administer multiple medications to multiple patients in limited time periods. For example, returning to the Aminophylline problem illustrated in Fig. 5, we observed proceduralised interactions between nursing students and their mentors during the commonly busy periods surrounding drug rounds (see Fig. 8).

Post-interaction student evaluations revealed that in situations like this, learners commonly failed to understand both the process and the logic employed to set-up and calculate dosage problems. The regular and predictable nature of the clinical act for staff effectively makes the calculation invisible to learners (Sabin, 2001; Weeks, 2001). Coben (2010) has suggested that some of these routinised practices may be the visible signs of ‘fast and frugal heuristics’, simple rules for making decisions with realistic mental resources (Gigerenzer et al., 1999). These experience-based techniques for rapid problem-solving can obscure the logic of expert internalized rules used in clinical problem-solving if they are not explained.

A combination of protracted immersion in classroom and clinical practice, engagement with students and a post-immersion serendipitous encounter with students finally triggered our
emergent understanding of the systematic pattern of conceptual errors that was previously elusive (Weeks et al., 2000; Lowes and Weeks, 2006). During this encounter it emerged that many students failed to construct a semantic link between the words used to describe dosage problems, e.g., the **Aminophylline** type injection problems (Figs. 5 and 8) and consistently set up MDC-PS equations incorrectly manifesting a conceptual error of the type illustrated in Figs. 6 and 7. However, the students were able to successfully understand the relationship between the elements of the problem and to set up subsequent dosage calculation problems correctly after exposure to a simple line drawing of the same medication dosage problem. The line drawing montage presented the three essential concrete elements of the problem in an iconic (picture) form mapped to the symbols (words and numbers) that represent them (see Fig. 9). It was this process that formed the basis of the authentic learning and assessment environments described within this series.

These encounters revealed that the combined nature of the classroom- and practice-based phenomena illustrated in Figs. 4, 5 and 8 creates a theory–practice gap that negatively affects the conceptualization of medication dosage problems for significant numbers of nursing students’ and which contributes to the manifestation of conceptual errors. Our findings resulted from planned insight, i.e., extensive review of previous work within this field, protracted immersion within classroom and clinical practice settings and significant interaction with students, coupled with unplanned events (Fine and Deegan, 1996). These combined to provide the intellectual and practice conditions necessary for us to discern previously unrecognized patterns and to understand the nature of the problem – as perceived by students... a set of contingencies that were previously hidden and unexplained. The need to understand the nature of these problems as perceived by students cannot be overemphasized. Due to limited experience, novices’ perceptions of phenomena and their approaches to problem-solving differ significantly from that of experts (Benner, 1984) and we return to this critical feature of education action research throughout this series. Weeks et al. (2013b,c), paper three and four of this series, evaluate the relationship between exposure to didactic and authentic learning environments and the manifestation of conceptual errors. Having identified this source of conceptual errors, we now turn to the origin, definition and diagnosis of calculation errors.

**The nature of arithmetical operation and computation errors**

An analysis of healthcare students’ numerical misconceptions and errors involving calculation skills has been reported in the professional literature for over 70 years (for example, Faddis, 1939; Pirie, 1987; Rayne and Bindler, 1988; Kapborg, 1992; Bliss-Holtz, 1994; Cartwright, 1996; Weeks et al., 2000; Grandell-Niemi et al., 2003; Jukes and Gilchrist, 2006; Eastwood et al., 2011). Work in the field suggests that these errors stem from arithmetical misconceptions generated during primary and secondary education. Tobias (1978) used the term ‘dropped stitches’ to describe how absence from school at a critical time or failure to understand a key mathematical concept, results in missing a link in the learning process. The analogy of a ‘dropped stitch’ in a knitted sweater which years later unravels due to the structural flaw, illustrates how previous misconceptions of the principles of division, or conversion of fractions to decimal equivalents etc, commonly present later as an unraveling of the individual’s computational performance when calculating medication dosages.

The UK Nursing and Midwifery Council and other international nursing regulators require educational institutions to assure themselves of prospective nursing students’ ability to become competent in the mathematics required for safe medicines administration (NMC, 2010a,b). Two essential types of calculation error observed during the 1992–2001 period of fieldwork and PhD research have been reported elsewhere and are summarized here (Weeks et al., 2000,2001):

a. Arithmetical operation errors — misunderstanding of arithmetical operations, e.g., dividing a fraction denominator by the numerator.

b. Computation errors — basic errors of multiplication and division etc.

**Arithmetical operation error exemplars**

Fig. 10 illustrates the inappropriate division of the fraction denominator by the numerator, calculating the solution as 2.5 mL (correct solution 0.4 mL). Fig. 11 illustrates essentially the same flawed schema (mental model) for this arithmetical operation. Note the classic misconception as the student initially sets up the division frame correctly, then crosses it out and demonstrates the same
especially in the novices Hutton might have been avoided via initial estimation of the answer (see Thompson and Logue, 2006). As mathematics education researchers Mike Askew and Dylan Wiliam have noted: Misconceptions theory serves as a basis for understanding the manifestations of a reverse operation. Additionally the student commits a computation error, calculating the solution as 2.1 tablets. This answer also demonstrates the dose measurement naivety (atypical measurement) created by didactic transmission methods of education (correct solution 0.5 tablet… note that splitting tablets is no longer recommended).

Computation error exemplar

As illustrated in Fig. 12, in contrast to arithmetical operation errors a computation error results in the correct operation being performed (in this case correct division of the numerator by the denominator); however a basic error of division etc is committed. Note in this example a clumsy or slip error of division is committed with a solution of 225 mL/h (correct solution = 125 mL/h), which might have been avoided via initial estimation of the answer (see Hutton’s Nursing Numeracy Taxonomy in Young et al. (2012), and careful post-computation checking of the answer. Note also the incorrect representation of the SI unit as mL (should read mL per hour).

Misconceptions theory

Research into ‘misconceptions’ is based on the tenet that novices’ conceptions commonly differ from those of experts, especially in the fields of mathematics and science (viz. Swan, 2001; Thompson and Logue, 2006). As mathematics education researchers Mike Askew and Dylan Wiliam have noted:

One of the most important findings of mathematics education research carried out in Britain over the last twenty years has been that all pupils constantly ‘invent’ rules to explain the patterns they see around them. (Askew and Wiliam, 1995)

The term misconception refers to a student conception that produces a systematic pattern of errors. Smith et al. (1993) argue from a constructivist standpoint that mere documentation of misconceptions does not advance our understanding of learning, or of how prior knowledge is transformed into more sophisticated forms. This premise is predicated by the principle that learning involves the gradual re-crafting of existing knowledge and that research should be directed at explaining and diagnosing the basis of students’ misconceptions, and supporting their reconstruction towards accurate schemata (mental models).

Between 1992 and -2005 as a part of the education action research process, the entry numeracy assessments and undergraduate written MDC-PS assessments of over 2000 nursing students across two universities in the UK and a mid-western university in the USA were analyzed and identified computation and arithmetical operation errors were classified. Comparisons with other error types reported in the field were carried out for consistency of error classification (Pirie, 1987; Shockley et al., 1989; Blais and Bath, 1992) and initial exemplar error classifications have been reported in previous work (Weeks et al., 2000, 2001).

Diagnosing the basis of calculation error types and supporting the transition from misconception to accurate schema construction

Smith et al. (1993) argue that the classification of calculation errors only goes part of the way towards providing an understanding of students’ misconceptions. Educators must also understand how these errors are committed and subsequently design a suitable diagnostic assessment that provides a mechanism to identify and support reconstruction of the mathematical ‘dropped stitches’ (Tobias, 1978; Farrell, 2006). We present a stratified 40-question five-point diagnostic multiple choice question (MCQ) assessment environment which:

1. Articulates the essential calculation skills that underpin medication dosage calculation problem-solving: division, multiplication, conversion of fractions to decimal equivalents, multiple computations and conversion of SI units (Young et al., 2013).
2. Presents the correct answer.
3. Presents the three most common arithmetical operation and computation errors manifested by prospective/pre-registration nursing students from our population.
4. Presents a ‘don’t know’ option. It is essential in diagnostic assessments that students who manifest misconceptions are not forced into guessing as this weakens the validity of the assessment.

Fig. 13 provides an example from the web-based assessment environment that expresses the features described above for the numerical calculation illustrated in Fig. 10.

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### Table 1: Computation error exemplar

<table>
<thead>
<tr>
<th>Drug</th>
<th>Prescribed Dose</th>
<th>Dispensed Dose</th>
<th>Contained in</th>
<th>How many tablets/capsules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Haloperidol</strong></td>
<td>2 mg</td>
<td>10 mg</td>
<td>2 ml ampoule</td>
<td></td>
</tr>
<tr>
<td><strong>Answer</strong></td>
<td></td>
<td></td>
<td></td>
<td>2.5 mL</td>
</tr>
</tbody>
</table>

**Fig. 10.** Arithmetical operation error: injection medication problem.

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### Table 2: Computation error exemplar

<table>
<thead>
<tr>
<th>Drug</th>
<th>Prescribed Dose</th>
<th>Dispensed Dose</th>
<th>Contained in</th>
<th>How many ml</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Captopril</strong></td>
<td>12.5 mg</td>
<td>25 mg</td>
<td>1 tablet</td>
<td></td>
</tr>
<tr>
<td><strong>Answer</strong></td>
<td></td>
<td></td>
<td></td>
<td>2 tablets</td>
</tr>
</tbody>
</table>

**Fig. 11.** Arithmetical operation error: tablet medication problem.
The example demonstrates the importance of the facilitator understanding the student’s errors, the classification of error committed and the common misconception underpinning the error. Understanding these manifestations has led to two crucial developments. Firstly, the diagnosis of the most common errors committed by prospective students has led to a useful basis for selecting meaningful distractors in a MCQ assessment. Understanding the basis of student misconceptions allows the educator to better understand these phenomena and provides meaningful distractors that originate from the root misconception (Brown et al., 1997; Weeks et al., 2000).

Second, students who select any of the incorrect answers have a mechanism for immediate feedback that has inbuilt diagnostic capacity. The diagnosed misconception provides students and their facilitators with a means to address inappropriate calculation schemata (incompetence) and a platform upon which to pick up mathematical dropped stitches and to reconstruct the flawed schema to one of calculation competence. This was a critical feature of the research and has other benefits. The assessment is constructed to represent the mathematical skills required for the UK Nursing and Midwifery Councils’ Essential Skills Cluster (NMC, 2010a) and other international nursing numeracy taxonomies. This type of assessment provides a fundamental diagnostic framework for both nurses’ general calculation competence and supports their calculation competence related to MDC-PS. Weeks et al. (2013b) and Macdonald et al. (2013) explore the critical requirement to diagnose arithmetical dropped stitches early in the professional career and to support the construction and crafting of accurate schema for calculation skills through structured support.

**Conclusion**

The definition, articulation, development, assessment and evaluation of competence are central to maintaining patient safety and education practice in the domain of medication dosage calculation problem-solving (MDC-PS). As the first component of the education action research process we have presented a MDC-PS competence model that illustrates the relationship between conceptual competence (dosage problem-understanding), calculation competence (dosage-computation) and technical measurement competence (dosage-measurement). This model helps to classify both competence and error diagnosis in MDC-PS.

In this paper we argue that the combination of didactic transmission methods of education and the ‘proceduralisation’ of medicines management in practice settings generates a theory—practice gap. This interferes with the construction of MDC-PS knowledge and skills, and contributes to conceptual errors. Secondly, we explore how misconceptions theory and the concept of mathematical ‘dropped stitches’ offer an explanation for the manifestation of calculation errors.

The facilitation of teaching and learning in calculation competence requires considerations and demands from both the learner and facilitator regardless of whether the learning takes place in practice or in classrooms. The literature continues to report medication errors relating to a lack of calculation competence in healthcare practice. To address this problem we present an approach centred on an exemplar calculation—skill diagnostic assessment framework. This framework is designed to assess and diagnose accurate schemata and common errors that are manifest in the fundamental computation and arithmetical operation skills employed in essential medication dosage calculation problem-solving.

However, we argue that in order to construct MDC-PS competence we must dispense with reductionist approaches that focus on calculation skill development in isolation. The need to co-locate conceptual, calculation and technical measurement competence development and assessment within authentic learning and diagnostic assessment environments is critical to solving this ubiquitous problem.

**Conflict of interest statement**

Professor Keith W Weeks, Norman Woolley & Lester Lewis are Directors of Authentic World Ltd, a spin-out company of the University of Glamorgan & Cardiff University. safeMedicate and eDose are trademarks of the MDC-PS authentic web-based virtual environments distributed respectively by Authentic World Ltd (UK and Ireland) and CAE Healthcare (International).

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References


Weeks, K.W., Lyne, P., Moseley, L., Torrance, C., 2001. The strive for clinical effectiveness in medication dosage calculation problem solving skills: the role of...
constructivist learning theory in the design of a computer based “Authentic World” learning environment. Clinical Effectiveness in Nursing 5, 18–25.


