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Design of a Mental Calculation App for Paramedic Students

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Paramedics need to perform drug calculations without the aid of a calculator, and meet high standards of accuracy, while in a time critical, high-pressure environment. Paramedic students, however, are not usually in the habit of maintaining their mental arithmetic skills when they first begin their course. Consequently, an MSExcel-based tool is under development that will assist students to help identify, maintain and enhance their mental arithmetic skills. In an attempt to meet the expectations of current students, the design borrows some basic elements of game design, gamification and mastery learning, and covers mathematical skills from simple arithmetic through to contextualised problem solving. This paper shows the design philosophy and needs analysis behind the app, and the methods employed to meet those needs. It also considers some novel challenges with regard to implementing the application within a course.

Key Words: paramedicine course, teaching mathematics, serious game, application design.

1. Introduction

Students enrolled in a paramedicine degree need to achieve mastery over drug calculations. In the field, paramedics perform calculations in a time critical, high-pressure environment, often without the aid of a calculator. Mistakes in the dose can be the difference between life and death of the patient, or may lead to the unnecessary prolonging of pain. Therefore, paramedic courses are designed to introduce and develop students' skills in performing drug calculations. Furthermore, most state ambulance services independently test the drug calculation skills of candidates prior to entry into the workforce.

A lack of fundamental skills in mathematics, however, can lead to difficulty in navigating the calculations, and has the potential to increase anxiety in students (Choudhary & Malthus, 2017). Paramedicine courses have traditionally expected students to have these skills, and have focused on further building the skills within the contextual content of drug calculations. However, it is unlikely that students, when they first enter their course, are in the habit of maintaining or improving their mental arithmetic skills. Consequently, a gap may exist between the skills the students have when they enter the course, and the skill level required to complete the course and

enter the workforce (Eastwood, Boyle, & Williams, 2012; Eastwood, Boyle, Kim, Stam, & Williams, 2015).

In the experience of the authors, several approaches have been tried to assist students in their journey towards performing competent drug calculations. These include providing the requisite information within the course, practice questions, worked examples, online quizzes, and even a parallel set of workshops for students covering relevant mathematical skills. However, low attendance to these workshops prompted the authors to consider alternative methods to meet the needs of the students. This led to the development of an MSExcel-based application that focused on the practice and possible development of mathematical skills for paramedics.

The design borrows some basic elements of gamification and game design (Dichev, Dicheva, Angelova, & Agre, 2014; Kapp, 2012a; Stott & Neustaedter, 2013) and mastery learning (Bloom, 1968, 1984), such as creating a sense of autonomy, lowering risk of failure, rapid feedback and creating a sense of progression (mastery). The content in the app covers a range of mathematical skills, from simple arithmetic through to contextualised problem solving. This paper initially focuses on a needs analysis of the students. It then covers the various elements of the current prototype, including user interface, game play, and feedback given by the app. It discusses the design philosophy about how these elements can meet student needs. Some strategies on how to distribute the app to students, and how the app can be applied within a paramedicine course are discussed.

2. Literature survey

2.1. Mathematics in paramedicine courses

In order to successfully negotiate drug calculations, student paramedics have to apply a range of basic mathematics skills, including mental operations (addition, subtraction, multiplication, division), fractions, percentages and decimals, ratios and proportions, algebra, unit conversions and worded problems (Bindler & Bayne, 1984; McMullan, Jones, & Lea, 2010). These are found within the first 10 years of the Australian Curriculum (Maths) (Australian Curriculum, Assessment and Reporting Authority [ACARA], n.d.). Since mathematics is compulsory until year 10 (National Curriculum Board, ACARA, 2009), course designers may consider it a reasonable expectation for students to have sufficient mathematical skills.

Evidence that students are assumed to have sufficient mathematical skills come from the following observations and investigations. First, we noted that Eastwood et al. (2015) reviewed the entry requirements of paramedicine courses in Victoria, finding few have mathematics as a prerequisite. This prompted a quick review of the entry requirements around Australia (Table 1), which showed that mathematics was a prerequisite to only two courses, with a further two allowing a mathematics subject to help prove the candidate's suitability to study the course. Only one course explicitly stated that knowledge of mathematics is assumed during the course but, to the knowledge of the authors, it is a learning requirement in the majority of most paramedicine courses.

Contrary to the above assumption however, both international and local studies which have looked at the mathematical skills of students entering into nursing and paramedicine courses, have found students generally did not have the expected basic mathematical skills (Bayne & Bindler, 1988; Bindler & Bayne, 1984; Eastwood et al., 2012, 2015; McMullan et al., 2010). For example, Eastwood et al. (2012) found the mean score of a basic mathematics test was 39.5%, while only 3 of 92 students achieved greater than 90% accuracy. A further study of first-year students (Eastwood et al., 2015) found similar issues with fundamental mathematical skills; however, this group was also assessed on their attitudes towards mathematics. An unexpected finding was the majority (63%) believed that they did not have any issue with mathematical calculations, despite the tests showing otherwise, and 90% saw few problems with their own educational history. It would seem

therefore, at least early in a paramedic course, there is a disconnection between the students' belief in their own mathematical abilities and their actual mathematical abilities.

Table 1. Mathematical requirements prior to entering a Paramedicine course* in Australia.

Courses with specified prerequisites	Number of courses
Mathematics is a prerequisite	2
Mathematics is an indicator of ability**	2
Mathematics not a prerequisite	12
Total	16

* The information for this table was obtained from state university entry bodies, including Victorian Tertiary Admissions Centre (VTAC, 2017), Queensland Tertiary Admissions Centre (QTAC, 2017), University Admissions Centre (UAC, 2017), Tertiary Institutions Service Centre (TISC, 2017), and university websites (Flinders University, 2017).

** Prerequisites for these courses have a list of 3 to 6 year-12 subjects and require the students to have completed two from the list. The list includes mathematics, but students can meet these requirements without completing the mathematics subjects.

2.2. Game design and gamification

Games have been used in education for many years, and there is a large body of research available that attest to their efficacy and to their limitations and potential pitfalls (Hays, 2005; Kapp, 2012a; Stott & Neustaedter, 2013; Van der Kooij, Hoogendoorn, Spijkerman, & Visch, 2015). With the rise of computer technology, game-playing has become a cultural norm in this generation, and even a form of addiction to some. However, despite the potential for computer technology to help enhance learning and the ground forged by the commercial games industry in the years since the 80s (Habgood, 2007), only recently have *serious games* and gamification become a rising trend within the Australian tertiary sector (Johnson, Adams-Becker, Cummins, & Estrada, 2014). Here, *serious games* are defined as games created to motivate players towards a serious outcome, such as education or behavioral change (Neill, 2009; Van der Kooij et al., 2015), and gamification is the implementation of game-like qualities into more traditional forms of education (Dichev et al., 2014; Kapp, 2012a).

Games are more likely to be effective at assisting learning when specific content is targeted and when they meet instruction objectives (Hays, 2005), and when they motivate the students to perform the requested tasks (Habgood, 2007; Kapp, 2012a). Stott and Neustaedter (2013) identified four concepts believed to be consistently successful for applying game design to learning. These include the freedom to fail, rapid feedback, and a sense of progression. (The fourth, storytelling, has limited relevance to this application.)

Freedom to fail is created by giving opportunities to start again without causing "irreversible damage" to the potential to attain the goal. This lowers the *risk of failure* towards achieving the goal, consequently encouraging risk-taking behavior, which moves the focus away from the consequences of the results and towards the process of learning (Stott & Neustaedter, 2013). This may have parallels in Control Value Theory (Roick & Ringeisen, 2017), by reducing the "relevance of failure". This also provides a form of autonomy, addressed in motivation theories such as proposed by Ryan and Deci (2017) and by Pink (2010).

Rapid feedback helps create a reflective feedback loop for students, therefore allowing students to speed up their recognition of what worked and what did not work. While feedback is already widely used in education, from looking in the back of the book for the answer to receiving results from tests, the speed of feedback within games is typically more rapid than in the classroom. This

is important because feedback should be both frequent and targeted to be effective for learning (Kapp, 2012b).

A sense of progression can be created by both intrinsic motives (e.g. by bettering oneself) or by extrinsic methods (e.g. by providing rewards for achievement). Intrinsic methods sustain motivation better than extrinsic methods, and extrinsic rewards may even provide a negative relationship with self-regulated learning and performance (Pintrich, 1999). However, the sense of progress, through completing small tasks, can lead to improved confidence and a greater likelihood to attempt more complex tasks (Kapp, 2012a).

3. Needs analysis

This needs analysis looks at the specific needs of paramedicine cohorts when refreshing and maintaining mathematics skills.

Paramedicine courses attempt to prepare students to meet the standards required for graduate entry positions within ambulance services. In most states, a numeracy test is included in the employment screening process. This assesses the candidates' ability to perform drug calculations and other numeracy skills required by ambulance officers, and it sets a stringent standard – 100% accuracy. It is to be completed without the use of a calculator – a restriction necessary to simulate real-world scenarios where calculations are made at incident sites. While there are some variations in the testing content from state to state (for example, the weight calculation and some drug doses), the actual mathematical requirements do not differ. The equations are universal for the solving of a drug calculation. Students are aware of these regional variations and should be able to adapt to them easily if they have the right skill set. While some of the specifics of drug calculations and associated physics and chemistry are covered within undergraduate courses, the mathematics skills to understand the equations are expected, despite few courses requesting mathematics as a prerequisite subject. Since the level of mathematics does not exceed that found in the year 10 Australian Curriculum, this expectation by university courses seems reasonable.

The timing of the initial introduction to drug calculations will vary from institution to institution. Since the majority of drug calculations are required in paediatric cases, it is common for universities to teach the skills in specific paediatric units. Subsequently, students may be introduced to drug calculations in their second year in the course. By this time, most students will have successfully transitioned into university study and typically understand the expectations of tertiary study, its pace of delivery and the expectations of self-starting and self-management of skill development. However, this means that a gap exists (at least a year) between performing calculations. Consequently, there is a recent trend towards integrating the numeracy components across all years in an effort to improve student outcomes as few students are in the habit of maintaining their mathematical skills. Furthermore, a large proportion of the students genuinely believe they have the requisite skills (Eastwood et al., 2015), and so may be unreceptive to suggestions that they need to improve. Therefore, for many students a disconnect exists between belief and actual skill level.

This belief is readily understandable. Most students have learned and developed the required skills in the past – most have completed at least year 10 mathematics courses, and most have had some form of maintenance of these skills, such as through the handling of money. It is the *maintenance* of some of the lesser used skills (such as long division and algebraic problem solving) that is the issue, not (usually) the comprehension of that skill itself. It is of little value to undermine the confidence that these students have in their own skills by pointing out this gap. Indeed, confidence and a belief that they can do the calculations is part of the mix that motivates students to learn and revise. So the primary need to address is how to close the skill gap *without* undermining the students' self-belief in their own mathematical ability.

4. Application design

The app is developed using a macro-enabled MSExcel-based spreadsheet. This means that any computer that has MSExcel can use the app, although there are slight differences between the Apple and MSWindows-based versions. Being a spreadsheet, the app can readily be located within an online learning platform and be distributed to students.

The app is based around timed practice sessions, found in the "Test" tab (Figure 1). The student firstly sets the skill level and type that they want to practice, and then starts a "Test". The "Test" requires them to complete as many problems as they can while the timer counts down from 60 seconds. These problems are randomly generated, and can be either a simple equation, such as show in Figure 1(a), or a worded problem. At the end of the test, the students are taken to a "Review" tab Figure 1(b), which gives immediate feedback about the student's performance. This includes: a summary of results, including how many they got right, how many they attempted, and the median time to answer the questions; and a table of individual question results, including the questions themselves, the correct answers and the answers given by the student, and the time taken to answer each question. This test provides a snapshot of the specific mathematics skill targeted by the level.
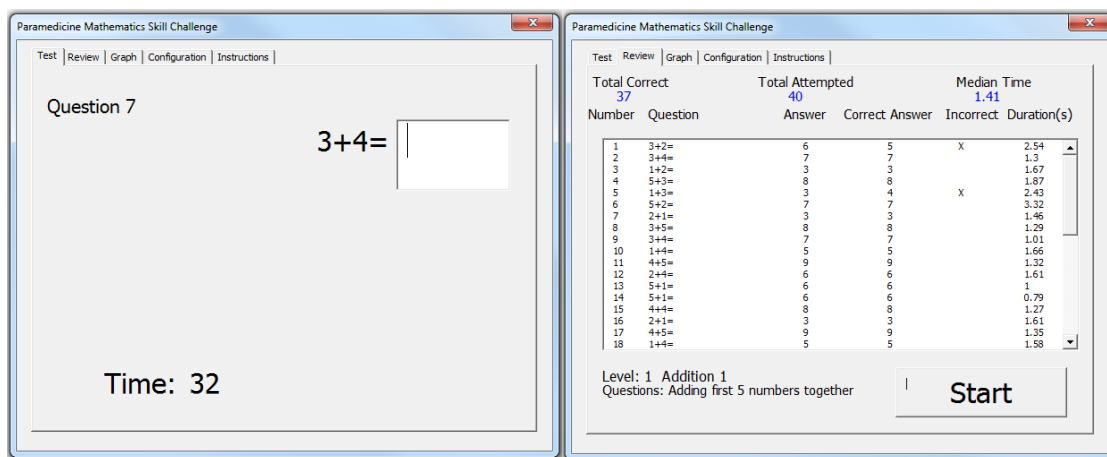

(a)   (b)

Figure 1. User interface for (a) "Test" tab, where the mathematical test questions are given, and (b) "Review" tab, where students obtain feedback on their most recent test.

From here, the students can either start a new test (by pressing the start button), or navigate to another tab. Additional tabs include an "Instructions" tab, a "Configuration" tab and a "Graph" tab. The "Instructions" tab gives an overview of the various tabs in the app, the "Configuration" tab allows the student to set the level they want to practice, and the "Graph" tab enables the student to review their history of test summaries via a range of graphs.

The "Graphs" tab provides a second form of feedback to the students – feedback about the long term progression of their skills (Figure 2(a)). Several possible graphs are available, showing the progression of the accuracy of skill and the speed of the skill as a function of attempt. A composite graph (Figure 2(b)) shows the achievement for the level in both accuracy (% correct) and speed (median time). This graph also shows achievement target lines.
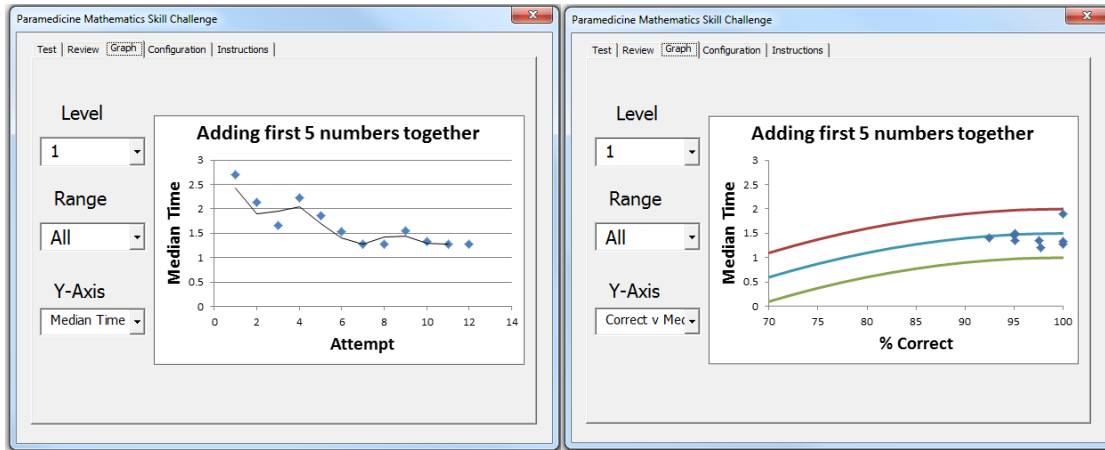
(a) (b)

Figure 2. Charts available on the "Graphs" tab. (a) Median time
vs Attempt number and (b) % Correct vs Median time.

The "Configuration" tab shows the current level, and a list of available skills and game levels (Figure 3). The skills are split into mathematical and medical calculation skills. Students begin with level 1 in the Addition/Subtraction column and level 12 in the Multiplication/Division column unlocked, and can progressively unlock further levels by reaching three levels of attainment (red, blue and green). The levels of attainment are met if the student scores below the colored target lines in Figure 2(b). To attain the blue (practiced) and green (mastered) achievements, the target line must be bettered in three or five consecutive tests respectively. The target lines depend upon the complexity of the skill, and therefore vary. The accuracy, however, is set to a minimum of 70%, and gets tougher as the levels increase. The medical calculation skills are only unlocked when all of the specific skills required for the calculations become available.
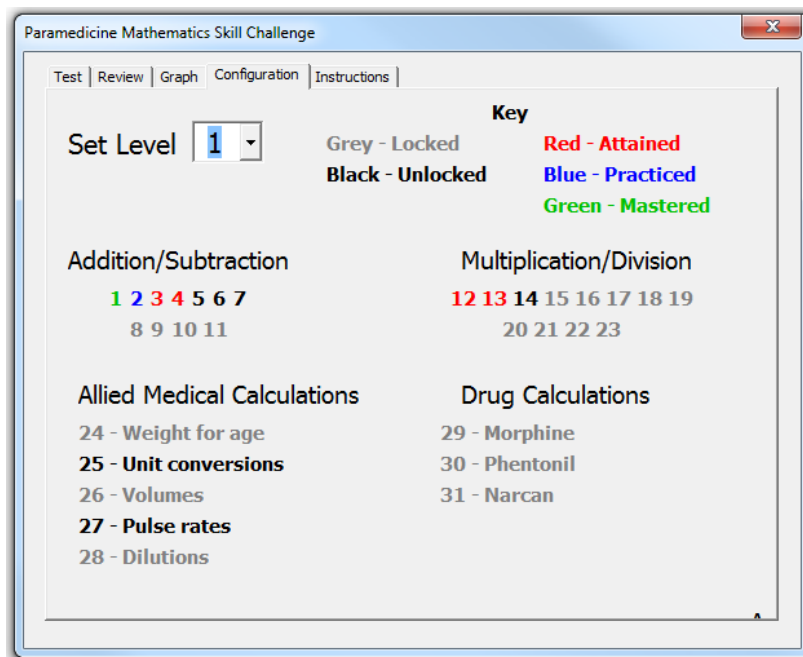

Figure 3. Configuration tab showing levels and achievements.

5. Discussion

5.1. Design rationale

The primary goal of paramedic courses is to prepare students for employment within the ambulance services of the various state health departments. The assessment requirements for those students wishing to undertake a graduate paramedic positon in one of Australia/New Zealand's ambulance services has grown to include a formalised computer based cognitive numeracy test, for example QAF (2017). Part of this industry assessment takes the form of a set of contextual drug calculations in a prescribed period, with a required accuracy of 100%. Paramedicine courses often offer a range of pedagogical approaches, from traditional (such as lectures) through to progressive (such as immersive simulations of emergencies), and so lecturers are generally open to the use of non-traditional methods, so long as they add value to students and have pedagogical merit.

These courses are confronted with two problems – a large proportion of students enter the course without sufficient currency with their mathematics skillset (even if they do have, or once had, the skillset) and a belief that they have the requisite skillset (Eastwood et al., 2012, 2015). Another, smaller group of students recognise that they do not have the skillset, and may even be afraid of mathematics. This means that within any cohort there will be students that perceive the action of revision as boring, while other students perceive it as daunting. On top of this, the competing demands on students' time, their work-life balance, the grades-focused approach of many students, and the lack of knowledge of how to develop their own mathematical skills mitigates against the students developing a revision program to improve their own mathematics skillset. Consequently, an expectation may exist among students that the necessary skillset will be acquired throughout the course, with only a limited focus on practice.

The guiding pedagogical principles behind the app are borrowed from mastery learning (Bloom, 1968, 1984). This pedagogy, which is summarised in Figure 4, suggests a sequential loop of formative testing and correction until the student has mastered the material. Much of this approach is student-centric, with individualised feedback and corrective procedures put in place. While this approach is sometimes used in primary and secondary schools, it is rarely used in tertiary education because it is considered non-scalable within the tertiary context.

The use of technology can help make some (and potentially all) of these steps scalable. This app focused on the testing and feedback steps, giving feedback about which questions were correct and incorrect immediately after each test. Currently, the app does not have the capability to develop corrective procedures (and its initial instruction is very limited), so the students will have to develop their own through reflective analysis of their feedback, or to seek help if they find they consistently get the questions incorrect. But the app is readily applicable for content already learnt by students, where revision and practice is the focus.

A key purpose of this app is to encourage students into the habit of revising and facilitating the practice of their mathematics skills. To do so, it firstly needs to provide opportunities for students to practice a broad array of mental arithmetical skills, set out in a way that also develops any student that does not yet have the required fundamental skills or knowledge of how to bridge the gap. Secondly, the app needs to have broad motivational appeal, that is, to encourage the students to regularly practice, irrespective of their current skills acumen.

To meet the first of these requirements, sets of targeted practice problems were provided. These focus on the foundational skills, from mental arithmetic through to the contextualised problems that are likely to be met both in the paramedicine service and on the students' exams. The problems were generated during the tests, using random values to ensure no two practice sets were the same. This provided a point of differentiation between this app and typical quizzes developed for LEO (Learning Environment Online, the Australian Catholic University's online learning platform), which had only limited ability to randomise the questions.
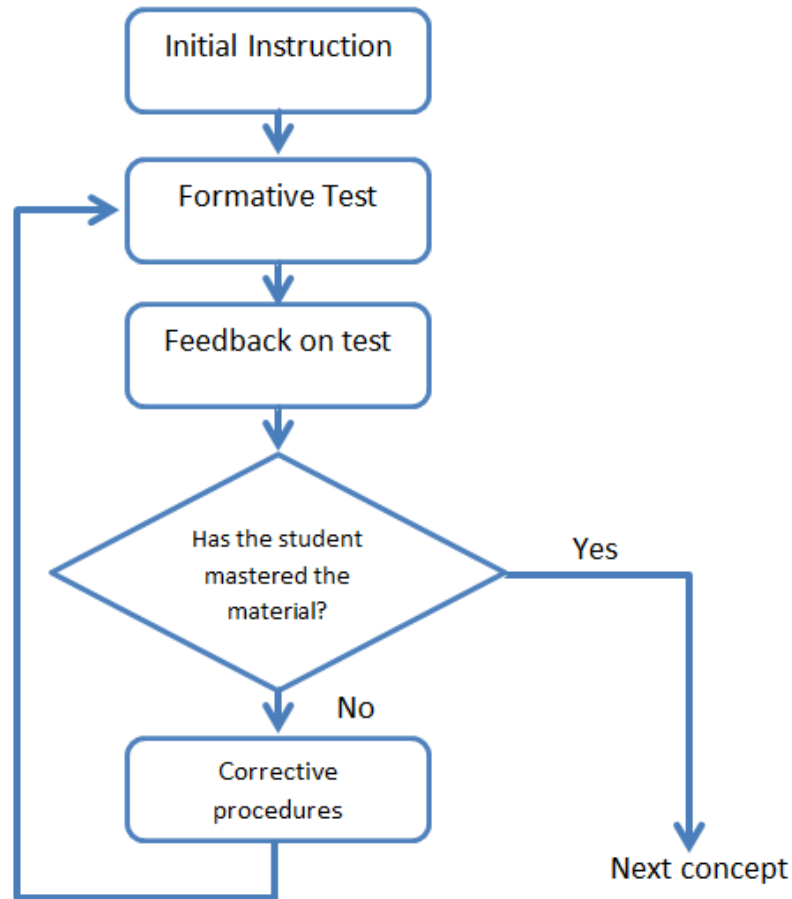
Figure 4. Formative loop towards mastery of subject matter (Bloom, 1984).

Problem sets were graduated into a series of "levels", with each level covering a new skill or more complex examples of the current skill. In line with mastery learning practice (Bloom, 1984), the student cannot move to the more complex skill without showing a minimum level of competency in the current skill. However, students that do prove high competence can advance through each level with as little as a single test. The medical calculations are locked until the students prove they have the prerequisite skills to attempt them.

Several methods were used to help motivate students to use the app regularly. Firstly, the app put an emphasis on speed by monitoring calculation times and feeding them back to the students. This is to sidestep the belief among students that they already have sufficient proficiency with the skills being tested, and therefore from making a value judgment about the potential to get bored. Since calculation speed can always be improved, this emphasis may also create an intrinsic motivation – that of beating their previous best speed. While accuracy is perhaps more important than speed, the emphasis on speed aimed to diminish a potential psychological completion point which may occur when achieving a maximum score (100%). While it is well known that an emphasis on speed may have a tradeoff with accuracy (Heitz, 2014), this approach was considered beneficial for the app for two reasons. Firstly, it mimics the time pressure that students will be under both in the field and in the numeracy test. It therefore adds a sense of authenticity to the practice – paramedics need to be able to handle time-pressure and timed practice helps build up that capability. Secondly, for the students who are initially overconfident, it will help reinforce an understanding of their need to practice.

Secondly, several forms of feedback, particularly about progression and mastery, are provided. After every test, the app automatically lands on the "Review" page, to provide immediate feedback about both accuracy and speed. Also, the "Graphs" tab shows the accuracy (% correct) and calculation speed (median time) against the number of test attempts. For example, a steadily decreasing median time shows the student improving their calculation speed. Students are encouraged to set personal targets and to see how far they can progress over time, and personal best times are shown on the graph.

The level system is also a conventional gaming form of feedback about progression (Dichev et al., 2014; Kapp, 2012a; Stott & Neustaedter, 2013), and was included in an attempt to provide an extrinsic sense of achievement and improve the confidence of the students (Kapp, 2012a). Students can see what level they have achieved, and how far they have to go to complete the skill set. To progress to the next level, a student must reach an accuracy/speed standard shown by the lines of the "Correct vs Median time" graph (Figure 2(b)). While progression through the levels can occur by achieving the lowest standard of achievement, "Attained", it can be sped up by meeting higher levels. This challenges the higher skilled students to perform better than the minimum levels and provides targets for developing students. The highest achievement standard, "Mastered", is set quite high, to prevent a premature loss of intrinsic motivation to repeat the level (Kapp, 2012a).

The medical calculation levels are deliberately positioned below the mathematics skills on the "Configuration" tab (Figure 3) for two reasons. Firstly, it reinforces the contextual goal of the app – that of performing medical calculations. Secondly, it serves to remind the students about the skillset that they need to master. Their initial locked status and the tooltips, accessed when hovering over the labels, provide a direct link between the prerequisites skills and the calculation. (E.g. "If I achieve "attained" for level 3 addition and level 14 multiplication, I'll open "Weight for age".")

5.2. Implementation options

The app was initially created as a tool that students could use to supplement their studies. However, it would gain greater utility if it were integrated as an active element of a paramedicine unit that introduced drug calculations. The initial and most passive method of implementation would be to set this alongside other resources in a first year unit's resource repository. But even if it were advertised by the course facilitators, it relies on the students themselves to download and use it. Past experience has shown that peripheral resources (i.e. those that are not essential to passing the course) are not commonly taken up by the students. Therefore consideration was given to making the app into an early hurdle task of the unit, following a similar path to the use of diagnostic tests in other courses. However, this is a rather direct and potentially heavy handed approach to dealing with the skill gap. Furthermore, the app is not currently equipped to deal with potential validation issues and IT security concerns that come with monitoring student performance, for which other platforms, such as a web-based application, would be preferred.

To address the issue of low take-up, moving some of the game elements into the unit, therefore partially gamifying the course structure, is an option. For example, a continuously updated leader board could be created, showing (volunteered) fastest times or current progress to the class. Also, rewards, such as a completion certificate or acknowledging the class champion, may be implemented. However, these elements can come with the risk of reducing the intrinsic motivation of the students by shifting the perception of the locus of control to an external source. Even positive rewards come with the risk of demotivating students (Deci, Vallerand, Pelletier, & Ryan, 1991), particularly if they are used too frequently (Kapp, 2012b).

Creating a discussion board about scores and tactics may help socialise the app, creating a form of peer acceptance and connectedness around the app. This can facilitate reflective learning, allowing peers (preferably) and tutors to discuss the various mathematical skills, problem solving techniques and their own role in achieving their study goals.

As this is early in the application development, the implementation process needs to be integrated with the development cycle. At the very least, a conduit for feedback from students about possible bugs should be created and the ability to redistribute upgrades to the students would be desirable. Additionally, feedback about current and potential new features would be highly recommended, as the students themselves will be in prime position to provide insight into their own learning and how the app could be improved. Once again, discussion boards within the unit's online platform may be an efficient way to provide this feedback.

6. Conclusion

A serious game app to assist paramedicine students in practising drug calculations and their fundamental mathematics skills has been created using MSExcel. This app performs tests of the students' calculation skills, and provides feedback regarding both the accuracy and speed of calculations. Several elements of the game were designed to motivate students to keep practising with the app, including: feeding back information about their progressive improvements; a graduated level system that aimed to improve the confidence of students as they progressed; and a series of achievements associated with each level that can be attained by meeting accuracy and speed objectives.

Some issues with implementation with a paramedic unit were discussed. As the app was considered to be an adjunct or support resource, take-up by students was low. This issue might be addressed by adding some gamification elements to the unit, but as yet it is too premature to have it used as a hurdle task. The app could readily be distributed through the unit's online platform, and this would also be helpful to socialise the app through the use of discussion boards. Further work may be needed, but it is currently at a stage where student feedback is necessary to prioritise potential improvements.

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