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SmartPrescription: A Principled Approach Towards Eliminating Prescription Errors in Healthcare

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Abstract: While it might deceptively appear that the major issues in medication concern medicine prescription calculations and the subtleness of conversions between measuring units, research in healthcare shows that the key issues relate to the context in which medication is prescribed. For instance, calculation of dose for the elderly is particularly sensitive especially in cases of repeat prescriptions whereby monitoring is crucial to avoid misuse. Initial (UK-based) primary research among four primary care surgeries and interviews with paediatricians indicated the lack of custom functions within existing information systems in a way that exploits knowledge about drugs, past prescriptions and patients' medical history. This paper presents the research we carried out towards addressing these issues. In particular, the paper presents a prototype software system developed that illustrates the efficacy of addressing medicine calculation issues where contextual information about drug, illness, and patient history are used to reliably inform the prescription process.

Keywords: medication errors, calculating doses, healthcare informatics.

1. Introduction

One of the aspects of patient safety that the National Health Service (NHS) in East of England, UK has actively been seeking to address is elimination of calculation errors in medication. This issue gained media attention (e.g. [1]) due to reports of toxicity to children and elderly patients, some of which were reported to have led to re-hospitalisation and fatalities. Initial primary research among four primary care surgeries, and interviews with paediatricians indicated the lack of custom functions within existing information systems to address calculation issues in a way that exploits knowledge about drugs, prescriptions and patients' history.

The work reported in this paper uses software engineering expertise to illustrate a research informed means to address these pertinent issues both within primary and secondary care. The key intent of the research was to empirically establish the extent of occurrence of harm to patients due to medication prescription calculation errors, and the extent to which existing healthcare software systems support the alleviation of these issues. To achieve the aims of the research, the focus of the proof of concept tool is to support prescription of medication to patients whilst ensuring synchronisation of treatment information between primary and secondary care using error-free dosage.

The paper is structured as follows: Section 1 introduces the research and aspects of patient safety that are pertinent to the project. Section 2 provides some background on incidents of prescription errors, medication errors and how computer based systems attempt

to address them. The research project's objective and methodology are covered in Sections 3 and 4 while Section 5 details the technologies used in our research. Section 6 provides a snapshot of our results during tests carried out in the field, Section 7 mentions our tool's business benefits and finally, Section 8 concludes the research paper.

2. Background

This section considers literature on medication errors in general, and in particular the most prevalent of such errors. The section also reviews ways in which dosage for children is calculated, as well as the nature of existing computer-based systems for supporting these activities.

2.1 Medication Errors

Errors are frequent in medical practice mainly owing to human nature and complexity of medical management [2]. The medication process involves three main areas of potential error. These are during the process of prescribing, dispensing and administering. These errors occur when human and system factors interact with the medication process (prescribing, dispensing and administering medication) to produce an unintended and potentially harmful outcome [3]. Approximately 1.3 million people are injured annually in the United States due to medication errors [4]. Furthermore, the most common medication errors in the USA are prescribing errors and this is estimated to be similar in the UK [5]. Medication errors are common in areas such as paediatrics and emergency departments [6]. Such errors lead to extended hospitalisation, unnecessary treatments and potentially death.

2.2 Prescribing Errors

From findings of empirical studies, some of the reasons attributed to occurrence of prescribing errors include inadequate knowledge of the patient and their clinical condition, inadequate knowledge of the drug, calculation errors, and poor history taking [7]. Prescribing errors in children are in particular caused by individualised dosing and calculation errors [8]. Such errors are more prevalent due to calculation mistakes such as incorrect placement of a decimal point, incorrect units and the wrong dosage routine [8].

Several studies have been performed looking into child dosage errors. In 2010 the BBC [9] reported on work done at the University of London in five London hospitals in 2005. The study indicated that of the 3,000 prescriptions studied over the period of two weeks, 13% showed an error and a third of these errors were dosing errors. Additionally, Cousins [10] performed a study in the UK using press reports over the period of eight years from 1993 to 2000. The study carried out an investigation on reports about occurrence of medication errors in children. The findings from the study documented 81 medication error incidents involving over a thousand children, from which there were at least 29 reported deaths. It was observed that the most frequent medication error involved an incorrect dose. Furthermore the paper states the difficulty in selecting the correct dose for children as there is a greater variation in the dose requirements as a child's weight typically varies from less than 1kg to more than 70 kg depending on age and physical size. From the study, a number of errors were observed. 9 of the 371 articles studied documented a decimal point error in the drug dose calculation resulting in 5 fatalities. One case involved a one day old premature neonate being given 15mg instead of 0.15mg morphine. If such a 100 fold error was to occur for an adult, it would most likely be detected as a large number of ampoules would be required whereas 15mg of morphine can easily be drawn up from two ampoules of the most dilute formulation available commercially.

2.3 Dosage Calculation for Children

Within paediatric care, dosage is usually calculated individually [8]. The main considerations are the patient's age, degree of prematurity in neonates, weight or body surface area and clinical condition. Due to the many variables that need to be taken into account, this leads to greater probability of dosing errors when prescribing for children. In the UK, drug doses are determined using the British Formulary [11], which stipulates that the dose for a child is stated as far as possible for the individual drug reference in the British Formulary. However, where information regarding the drug is not available the dose must be calculated. Generally, the dose is calculated based on body weight (in kilograms) for children aged twelve years and younger. Children's doses for many drugs are standardised by weight (some doses also take into account the child's age). Therefore, the mg/kg dose is multiplied by the body weight (in kg). Ginzburg [12] studied the effect of using a computerised prescribing system that calculated the dose for children by the weight based calculation. However, in cases where children were obese, the dose was based on the adjusted body mass (ABM). Equation 1 details the calculation used:

$$ABM = \frac{[Height\ in\ cm^2]x\ 1.65}{1000}$$

Equation 1: Calculation of Adjusted Body Mass

This was performed to prevent overdosing of obese children. The study showed a noticeable reduction in prescribing errors (from 32.6% to 20.5%) due to the use of the weight based computerised dose calculation system. The doses are occasionally standardised by Body Surface Area (BSA). An estimate by this method is regarded by the British Formulary as being preferable to body weight calculations, as many physiological phenomena correlate better with BSA. Within the British National Formulary (BNF), the BSA is calculated using the DuBois formula [13]. The DuBois formula is shown in equation 2 below:

$$S = W^{0.425} x\ H^{0.725}\ x\ 71.84$$

Where:

S = surface area (cm^2), W = Weight (kg), H = Height (cm).

Equation 2: DuBois calculation of BSA

2.4 Computer-based Systems

Computerised systems have been developed to help in the reduction of prescribing errors. The Food and Drug Administration (FDA) has stated that systems such as the Computerised Physician Order Entry (CPOE) system have been shown to be effective in reducing medication errors. This particular system involves medication orders being entered into the computer system. The medical director at the Children's hospital of Pittsburgh observed that the system ensured "there is no misinterpretation of handwriting, decimal points, or abbreviations" [14]. The system also requires the weight of the child being treated to be entered into the system, without the weight an order cannot be submitted. The system improved prescribing activity since no order would be submitted or processed without weight being entered into the system.

Kirk [15] documented a study performed at a university teaching hospital in the paediatric unit in 2003 for a six month period. The hospital used a computer clinical decision support system, which for the study was modified in order to allow doctors to select between using the traditional prescription method or using the enhanced computer calculated dose system. Prescription errors were classed as an under dose, an overdose, an

excessive total daily dose or no dose being prescribed. The Paracetamol calculation was based solely on the child's weight, whereas the Promethazine calculation had to take both weight and age into account. The system required the weight of the child to be entered into the system. The traditional method involved the doctor typing the prescription into the relevant fields in the system. The computed calculated dose system was activated if the doctor picked it from a drop down list or typed the drug name and then picked the drug dosage form from a drop down list. The system would then calculate the dose based on 10mg/kg for Paracetamol and 0.2mg/kg for Promethazine. The value was then adjusted for the dosage form, keeping within the dosage limits. The dosage limits for the two drugs were as follows:

- Paracetamol: 10-15mg/kg and a maximum daily dose of 60mg/kg/day
- Promethazine: 0.2-0.5mg/kg (the maximum daily dose was not defined)

The system did, however, allow the recommended computer calculated dose to be altered by the doctor. If the altered dose was outside of the dose limits, a warning to the doctor would be shown detailing this fact. However, the doctor could choose to ignore this warning and the computer calculated dose system could still result in medication errors. The study analysed 4,274 prescriptions and the traditional prescription method error was 28.2% compared to the computer calculated dose method error rate of 12.6% (a ratio of 2:1). All of the medication errors in the computer calculated dose results were due to doctors deciding to manually alter the computer calculated dose and then ignoring the resulting warning. Resulting from this study, key improvements to the system were recommended such as:

- Making the system inflexible so that doctors could not override system decisions/warnings. However, doing this may make risk the rejection of the system due to its rigidity.
- Improving the wording of the warning to alert the physician to the gravity of the medication error that could occur if the warning is ignored.
- Adding further drugs to the system so that drug dose calculations can be performed for 80% of all paediatric prescriptions.

In another study, [16] reported that in a paediatric critical care unit, computerised prescribing reduced prescription errors by 99% (from 30.1% to 0.2%) in 13,828 medical orders written for 514 patients. The paper, however, did outline the potential failures of computerised Physician Order Entry systems due to their complex modelling of diagnosis and treatment. According to [16], CPOE usage actually increased the number of adverse drug events, and the system's lack of flexibility was emphasized. The conclusion was that accessibility of the user interface of these systems is critical to prescribing medicines correctly.

3. Objective

There are significant efforts to address the issue of toxicity arising from calculation errors in medication. The main problem with many of the efforts, especially software support, is the extent to which many of the systems seem to be mere data processing systems, as opposed to systems that make real-time, intelligent use of the data to inform clinicians of real implications of given doses. From the above literature review, there is a definite need to improve on existing efforts as a means towards reducing medication errors particularly in the treatment of children where such errors can prove fatal. The next section details our approach and research methodology aimed at alleviating the weaknesses identified above.

4. Methodology

The main source of knowledge regarding the significance of medicine calculation errors was interviews with General Practitioners (GPs) at 4 primary care surgeries within Dorset, UK. The interviews were mainly geared towards eliciting information regarding:

a) The extent of prevalence of prescribing and dose errors within their surgeries and any general information on the same nationally.
b) The extent to which there is computer system support for obviating occurrence of these errors.

Further interviews were conducted within 2 hospitals and 3 pharmacies within Dorset, UK. These interviews were aimed at obtaining information about the issues mentioned above, but with a focus on paediatric care. Findings from the above interviews seemed to support evidence from literature, that there are many critical occurrences of medication errors, and that existing computer-based systems do not provide adequate support for elimination of prescription and dose errors. To appreciate the size and complexity of the BNF / BNFc, every drug listed has such types of information about it as indications, cautions, adverse drug interactions, contraindications, hepatic impairment, renal impairment, pregnancy and breastfeeding and Adverse Drug Reactions (ADR). An account with the BNF and BNFc was setup, and the information from the online source studied. The area of particular interest within the individual drug listings was the dose section. For the purposes of this work, Aspirin was used as the main example.

5. Technology Description

The entire research, problem identification, requirements analysis, design and prototype development process involved the use of modelling and development tools such as Unified MarkUp Language (UML) and Java to ensure platform-independence. The following subsections detail the requirements analysis, system design processes, the software prototype's application logic design and a snapshot of the software tool's functionality.

5.1 Requirements Analysis

Like with many research problems, knowledge on existing problems within this domain was acquired via literature analysis. However, further insight was gained and requirements elicited from stakeholders, mainly medical practitioners as mentioned in previous sections. Recording of requirements was mainly via the use of a laptop computer after which an initial use case model was produced. The use case was shared with the interviewed medical practitioners for validation. There were requirements gathering and analysis process involved 3 iterations of the use case model before arriving at a final one. The analysis phase also involved producing a data model, typically, an Entity-Relationship (E-R) model of drugs, prescriptions and various stakeholders (patients and medical practitioners). This initial data model was mainly a domain model (based on the BNF documentation), which was further developed at the design stage. Part of design involved consideration of interface design, access to the data model as well as design of key objects for managing application logic. The design elements artefacts will be presented in the next sub-section.

5.2 System Design and Application Logic

They key design decisions were to construct a data model, with subsequent development into a database system. Construction of E-R models therefore followed a database implementation using MySQL relational database system. The main architectural pattern chosen was an n-tier architecture to enable scalability and flexibility in the initial design

and possible adaptations in the future. The design of the data access was done using UML class diagrams, which were organised using packages. The main packages are Logic, GUI and Data. Like the E-R model, the class diagram is large, and was also constructed via four iterations. In creating UML design class diagrams, the aim was to orient the development to the Java programming language. Hence, the main objects in the class diagram are mapped to the key domain model elements in the E-R model. The key consideration for selection of Java as the implementation platform is its ubiquitous nature, and the fact that conversion between a standalone based prototype to a web-based application is easy. Additionally, Java has a rich library for handling database access and manipulation, as well as native libraries for exception handling.

5.3 Software Prototype

The software prototype developed provides several fundamental features for adding new patient record, modification, as well as support for look-ups or searching. These are expected features but this paper's main concern was intelligent prescribing features that are informed by the type of drug and concerned illness, as well as patient history and often unique paediatric characteristics. For example, if a patient were on a subsequent visit to a GP surgery, the following interface would be used for considering his/her appropriate prescription.

The above screen displays the date and time stamp of when the patient record entry was created (the time the *Add* button was clicked). The screenshot in Figure 1 below shows the general patient information including the patient's calculated age. Alongside the date and time stamp, these fields are un-editable. The patient's weight and height data fields can be written to and the *Notes* section provides the clinician with a feature to enter details about the patients visit. The symptoms section allows a user to search for a symptom that the patient is describing. The matching symptoms are displayed which can then be recorded.

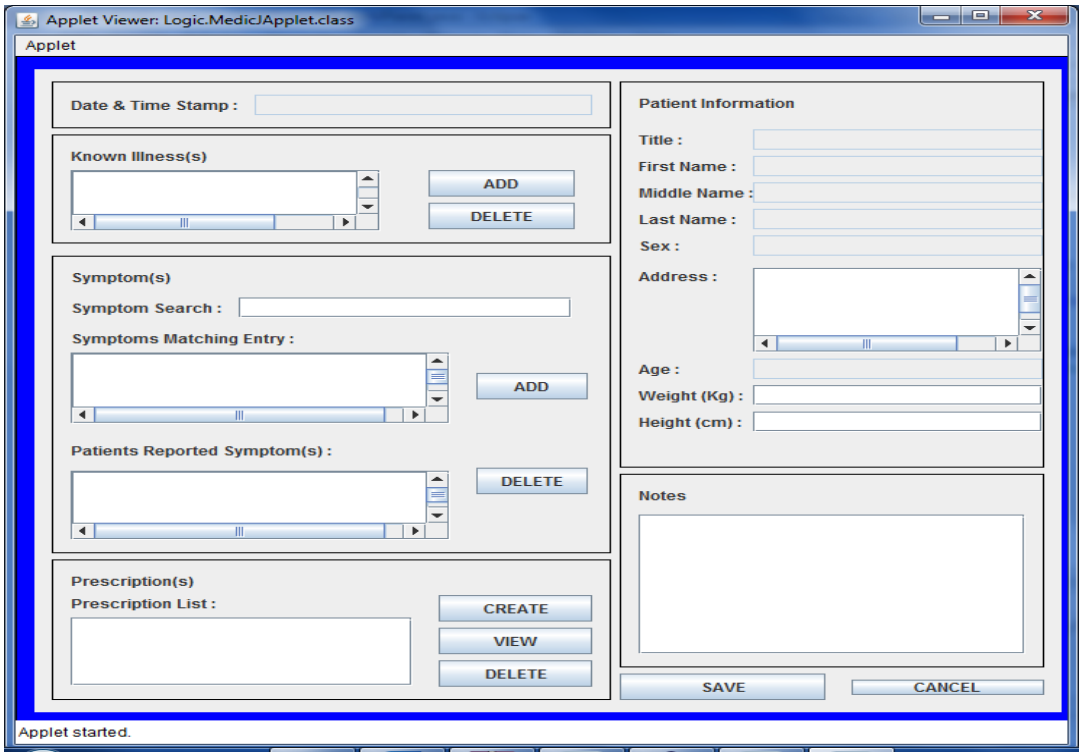

Figure 1: GUI for Patient on first Visit to Surgery

The *Prescription* section contains a list showing a patient's previous prescriptions. The user can then click on a prescription from the list and view the prescription. Clinicians can

also create new prescriptions and have access to a choice of drugs from which they can type a drug's (partial or complete) name.

6. Results

The main Use Cases for the application were realised in the implementation during the first development iteration. There was significant confidence in the functionality based on non-real world test data. The main stakeholders - 6 GPs from two primary care surgeries, and 4 paediatricians from two hospitals were subsequently requested to test the software system. The key areas of trial were ease of access of the user interface, and the extent to which the application performed key functions as described in the Use Cases. The following table provides a summary of the views of the users at the initial testing phase regarding key functions provided by the software prototype system and the accessibility of the interface to perform the functions.

Table 1: *Experiences within problem domain*

Feature	**No. of Users**	**Adequate Functionality? (Yes/No)**	**Features Accessible? (Yes/No)**	**Comments**
Create prescription (Select dose form)	5 GPs 4 Paediatricians	Yes	Yes	None
Create prescription (Add dose amount)	6 GPs 4 Paediatricians	Yes	No – 2 GPs and 1 Paediatrician. 2 GPs and 1 Paediatrician expressed dissatisfaction as shown in comments.	Inflexibility; doctor should be allowed to override warnings
Create prescription (Add drug)	6 GPs 4 Paediatricians	Yes	Yes	None
Create prescription (Add dosage)	6 GPs 4 Paediatricians	Yes	No – same 2 GPs and 1 Paediatrician expressed similar dissatisfaction	Inflexibility; doctor should be allowed to override warnings
Modify prescription (modify dosage)	6 GPs 4 Paediatricians	Yes	No – same 2 GPs and 1 Paediatrician expressed similar dissatisfaction	Inflexibility; doctor should be allowed to override warnings
Modify prescription (modify drug)	6 GPs 4 Paediatricians	Yes	Yes	None

The inflexibility indicated by the clinicians was with regard to the system not allowing given combinations of drugs on the same dosage, and not allowing some amounts of drugs to be prescribed. The clinicians argued that there should be flexibility in the system to allow these medical rules to be overridden where necessary. This change was effected as requested and tested in the subsequent development phase. The other experience that was positive and well received was synchronisation of medical information between healthcare points. Two paediatricians simulated a treatment, which was updated automatically in real-time at two of the participating GP surgeries. Further work will involve working to make the software system more scalable and secure.

7. Business Benefits

Due to continued development of new drugs, a scalable software system is crucial to building a progressive knowledgebase of drugs that integrates with smart prescription components to support informed medicine calculations. A significant future work is the scaling up of the integrated healthcare system, which provides seamless sharing of data on real-time basis between primary and secondary care provision centres. The issue at the moment is the lack of a national patient record database system across all healthcare points. However, the work done within Dorset illustrates the efficacy of this concept.

8. Conclusion

The significance of an integrated medical information system is vital especially in treatments that arise due to referrals between primary and secondary care and even for follow-on treatment. A key use for calculations based on smart referencing of drugs and prescriptions is within paediatrics, elderly care, and opiates. The key issue in all these circumstances is not merely the storage and access of data, rather, the interrogation of such data to make sense of appropriate and safe treatment of patients.

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