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An investigation of healthcare professionals' experiences of training and using electronic prescribing systems: four literature reviews and two qualitative studies undertaken in the UK hospital context

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An investigation of healthcare professionals' experiences of training and using electronic prescribing systems: four literature reviews and two qualitative studies undertaken in the UK hospital context

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Abstract

Electronic prescribing (ePrescribing) is the process of ordering medicines electronically for a patient and has been associated with reduced medication errors and improved patient safety. However, these systems have also been associated with unintended adverse consequences. There is a lack of published research about users' experiences of these systems in UK hospitals. The aim of this research was therefore to firstly describe the literature pertaining to the recent developments and persisting issues with ePrescribing and clinical decision support systems (CDS) (chapter 2). Two further systematic literature reviews (chapters 3 and 4) were then conducted to understand the unintended consequences of ePrescribing and clinical decision support (CDS) systems across both adult and paediatric patients. These revealed a taxonomy of factors, which have contributed to errors during use of these systems e.g., the screen layout, default settings and inappropriate drug-dosage support. The researcher then conducted a qualitative study (chapters 7-10) to explore users' experiences of using and being trained to use ePrescribing systems. This study involved conducting semi-structured interviews and observations, which revealed key challenges facing users, including issues with using the 'Medication List' and how information was presented. Users experienced benefits and challenges when customising the system, including the screen display; however, the process was sometimes overly complex. Users also described the benefits and challenges associated with different forms of interruptive and passive CDS. Order sets, for instance, encouraged more efficient prescribing, yet users often found them difficult to find within the system. A lack of training resulted in users failing to use all features of the ePrescribing system and left some healthcare staff feeling underprepared for using the system in their role. A further literature review (chapter 5) was then performed to complement emerging themes relating to how users were trained to use ePrescribing systems, which were generated as part of a qualitative study. This review revealed the range of approaches used to train users and the need for further research in this area. The literature review and qualitative study-based findings led to a follow-on study (chapter 10), whereby the researcher conducted semi-structured interviews to examine how users were trained to use ePrescribing systems across four NHS Hospital Trusts. A range of approaches were used to train users; tailored training, using clinically specific scenarios or matching the user's profession to that of the trainer were preferred over lectures and e-learning may offer an efficient way of training large numbers of staff. However, further research is needed to investigate this and whether alternative approaches such as the use of students as trainers could be useful.

This programme of work revealed the importance of human factors and user involvement in the design and ongoing development of ePrescribing systems. Training also played a role in users' experiences of using the system and hospitals should carefully consider the training approaches used. This thesis provides recommendations gathered from the literature and primary data collection that can help inform organisations, system developers and further research in this area.

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Glossary and List of Abbreviations

ACE inhibitor	*Acetyl Cholinesterase Inhibitor*
ADE	*Adverse Drug Event*
AKI	*Acute Kidney Injury*
AMIA	*American Medical Informatics Association*
BID	*Twice a day*
BNF	*British National Formulary*
CB	*Clare Brown*
CDS	*Clinical Decision Support*
CKD	*Chronic Kidney Disease*
CLT	*Clare Louise Tolley*
COX 2 inhibitor	*Cyclooxygenase-2 inhibitor*
CPOE	*Computerised Provider Order Entry*
CPOEMS	*Computerised Prescriber Order Entry Medication Safety*
DDI	*Drug-Drug Interaction*
EHR	*Electronic Health Record*
EPMA	*Electronic Prescribing and Medication Administration*
ePrescribing	*Electronic Prescribing*
FY1 or 2	*Foundation Year 1 or 2 (junior doctor)*
g	*Gram*
GI	*Gastrointestinal*
GKI Infusion	*Glucose, Potassium and Insulin Infusion*
GTN	*Glyceryl Trinitrate*
HITECH Act	*The Health Information Technology for Economic and Clinical Health Act*
HSRPP	*Health Services Research and Pharmacy Practice*
HM	*Helen Mulcaster*
I.u	*International Unit*
ICU	*Intensive Care Unit*
INR	*International Normalised Ratio*

IT	Information Technology
IV	Intravenous
KC	Katherine Coffey
Kg	Kilogram
KT	Katherine Triffitt
LCP	Liverpool Care Pathway
Mg	Milligram
MI	Myocardial Infarction
ml	Millilitre
MRSA	Methicillin-resistant Staphylococcus aureus
NF	Niamh Forde
NHS	National Health Service
NOAC	Novel oral anticoagulant
NPSA	National Patient Safety Agency
NSAID	Nonsteroidal anti-inflammatory drugs
PD peritonitis	Peritoneal-dialysis related peritonitis
PICS	Prescribing Information and Communication System
PO	Oral administration
POCT	Point of Care Test
PPI	Proton pump inhibitor
PRN	When required
QAM	Every morning
QD	Four times a day
SGIM	Society General Internal Medicine
SHO	Senior House Officer (speciality trainee doctor)
SPS	Sarah Patricia Slight
STAT	Immediately
TID	Three times a day
TPMT	Thiopurine S-methyltransferase
UK	United Kingdom
US	United States

Declaration

This work has not been previously submitted for a degree and is not based on joint research.

Statement of Copyright

"The copyright of this thesis rests with the author. No quotation from it should be published without the author's prior written consent and information derived from it should be acknowledged."

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Dedication

I dedicate this thesis to my parents, Joan and Peter Brown. Without your unwavering support over the years and showing me what can be achieved with hard work and dedication, this PhD would not have been possible.

About the Author

Clare Tolley (nee Brown) graduated from the University of Sunderland in 2012 with a First Class Master of Pharmacy degree. She then completed her pre-registration year at Oxford University Hospitals NHS Foundation Trust before successfully passing the General Pharmaceutical Council's registration exam to qualify as a registered pharmacist in 2013. Clare worked as a clinical pharmacist at Northumbria Healthcare NHS Foundation Trust for 9 months and during this time obtained a Post-graduate Certificate in Clinical Pharmacy from Queen's University Belfast. Clare began her PhD at Durham University in 2014; during this time she has contributed to undergraduate teaching on the MPharm course, co-planned and delivered a successful Sutton Trust Summer School and helped co-organise a regional pharmacy practice conference and the Health Services Research and Pharmacy Practice (HSRPP) annual conference in 2018. The author has also published four articles in international peer-reviewed journals, presented her work at both national and international conferences, including the American Medical Informatics Association (AMIA) annual conference and has contributed to the preparation of a report that was submitted to Health Education England Kent, Surrey and Sussex.

Publications

Journal Papers

Tolley, CL., Slight, SP., Husband, AK., Watson, NW., Bates, DW., (2018) *Improving Medication-Related Clinical Decision Support.* American Journal of Health System Pharmacy *75(4):239-246. doi: 10.2146/ajhp160830.*

Tolley, CL., Forde, NE., Coffey, KL., Sittig, DF., Ash, JS., Husband, AK., Bates, DW., Slight, SP., (2017) *Factors contributing to medication errors made when using computerized order entry in pediatrics: A systematic review.* Journal of the American Medical Informatics Association *25(5):575–584* https://doi.org/10.1093/jamia/ocx124

Brown, CL., Mulcaster, HL., Triffitt, KL., Sittig, DF., Ash, J., Reygate, K., Husband, AK., Bates, DW., & Slight, SP. (2017) *A Systematic Review Of The Types And Causes Of Prescribing Errors Generated From Using Computerized Provider Order Entry Systems in Primary and Secondary Care*. Journal of the American Medical Informatics Association *24 (2): 432-440*

Brown, CL., Reygate, KL., Slee, A., Coleman, JJ., Thomas, SK., Bates, DW., Husband, AK., Watson, NW., Slight, SP. (2016). *A literature review of the training offered to qualified prescribers to use electronic prescribing systems: why is it so important?* International Journal of Pharmacy Practice *25: 195-202 doi: 10.1111/ijpp.12296.*

Reports submitted

Slight, SP., **Brown, CL.,** Husband, AK., Slee, A., Coleman, JJ., Pontefract, SK. (2015) *Electronic Prescribing Systems and the Training Offered to Prescribers: Safe Prescribing Project*, A Report submitted to Health Education Kent, Surrey and Sussex.

Journal papers in preparation

- **Tolley, CL.,** Husband, AK., Watson, NW., Slight, SP. (2018) What are the benefits and challenges of customising a commercial electronic prescribing system?

- **Tolley, CL.,** Husband, AK., Watson, NW., Slight, SP. (2018) The training approaches used to educate clinicians on the use of a commercial electronic prescribing system.

Abstracts Accepted

Tolley, CL., Watson, NW., Heed, A., Husband, AK., Bates, DW., Slight, SP. (2018) What are the benefits and challenges of customising a commercial electronic prescribing system? A qualitative study. *The 24th Health Services Research and Pharmacy Practice (HSRPP) Conference, 12th & 13th April 2018*, Newcastle, England. [Oral presentation].

Tolley, CL., Watson, NW., Heed, A., Husband, AK., Bates, DW., Slight, SP. (2017) Approaches to customisation of a commercial electronic prescribing system: the benefits and challenges, *Royal Pharmaceutical Society Winter Summit, 5th December 2017,* London, England.

Tolley, CL., Forde, NE., Coffey, KL., Sittig, DF., Ash, J., Husband, AK., Bates, DW., Slight, SP. (2017) Medication Errors Generated When Using Computerized Provider Order Entry Systems in Pediatrics: A Systematic Review, *The 41st American Medical Informatics Association (AMIA) Annual Symposium, 4th – 8th November 2017,* Washington D.C., United States.

Tolley, CL., Watson, NW., Heed, A., Husband, AK., Bates, DW., Slight, SP. (2017) Customization of a Commercial CPOE System to Improve Patient Safety. *The 41st AMIA Annual Symposium, 4th – 8th November 2017,* Washington D.C., United States.

Tolley, CL., Watson, NW., Heed, A., Husband, AK., Bates, DW., Slight, SP. (2017) Customization of a Commercial CPOE System to Improve Patient Safety, *The 34th International Society for Quality in Health Care (ISQua) Conference, 1st- 4th October 2017,* London, England.

Tolley, CL., Forde, NE., Coffey, KL., Sittig, DF., Ash, J., Husband, AK., Bates, DW., Slight, SP. (2017) The Types and Causes of Medication Errors When Using Computerized Provider Order Entry Systems in Pediatrics: A Systematic Review, *The 40th Society of General Internal Medicine (SGIM) Annual Conference, 19th-22nd April 2017,* Washington D.C., United States.

Tolley, CL., Watson, NW., Heed, A., Husband, AK., Bates, DW., Slight, SP. (2017) The benefits and challenges of customising a commercial CPOE system in large U.K. teaching hospital, *The 40th SGIM Annual Conference, 19th-22nd April 2017,* Washington D.C., United States.

Brown, CL., Mulcaster, HL., Triffitt, KL., Sittig, DF., Ash, J., Reygate, K., Husband, AK., Bates, DW., Slight, SP. (2017) The Types And Causes Of Prescribing Errors Generated From Using Electronic Prescribing Systems in Primary and Secondary Care: A Systematic Review, *The 23rd HSRPP Annual Conference, 10th – 11th April 2017,* Reading, England. [Oral presentation]

Brown, CL., Reygate, K., Slee, A., Coleman, JJ., Thomas, SK., Bates, DW., Husband, AK., Watson, NW., Slight, SP. (2016) A Literature Review of The Approaches Used to Train Qualified Prescribers to Use Computerized Provider Order Entry Systems, *The 40th AMIA Annual Symposium, 4th – 8th November 2016,* Chicago, IL, United States

Brown, CL., Mulcaster, HL., Triffitt, KL., Sittig, DF., Ash, J., Reygate, K., Husband, AK., Bates, DW., Slight, SP. (2016) A Systematic Review of The Types And Causes Of Prescribing Errors Generated From Using Computerized Provider Order Entry Systems in Primary and Secondary Care, *The 40th AMIA Annual Symposium, 4th – 8th November 2016,* Chicago, IL, United States.

Brown, CL., Triffitt, KL., Mulcaster, HL., Sittig, DF., Ash, J., Reygate, K., Husband, AK., Bates, DW., Slight, SP. (2016) What Are The Types and Causes of Prescribing Errors Generated from Using Electronic Prescribing Systems? A Systematic Review. The 45th Society for Academic Primary Care (SAPC) Annual Scientific Meeting, 6th–8th July 2016, Dublin, Ireland. [3-minute presentation]

Brown, CL., Mulcaster, HL., Triffitt, KL., Husband, AK., Slight, SP. (2016*)* The Types and Causes of Prescribing Errors Generated from Using Electronic Prescribing Systems: A Systematic Review, *The 39th SGIM Annual Conference, 11th – 14th May 2016*, Hollywood, FL, United States. [Oral Presentation]

Brown, CL., Reygate, K., Slee, A., Coleman, JJ., Thomas, SK., Bates, DW., Husband, AK., Watson, NW., Slight, SP. (2016) A review of the literature on the approaches used to train qualified prescribers to use electronic prescribing systems, *The 22nd HSRPP Annual Conference, 7–8 April 2016,* Reading, England. [Poster presentation winner]

Brown, CL., Reygate, Katie., Slee, A., Coleman, JJ., Thomas, SK., Bates, DW., Husband, AK., Watson, NW., Slight, SP. (2016) A review of the literature on the approaches used to train qualified prescribers to use electronic prescribing systems, *The 27th Prescribing and Research in Medicines Management (UK & Ireland) (PRIMM) Annual Conference, 29th January 2016*, London, England.

Brown, CL., Slight, SP., Husband, AK., Watson, NW., Bates, DW. (2015), A Literature Review of Medication-Related Clinical Decision Support, *The 39th AMIA Annual Symposium, 12th − 16th November*, San Francisco, CA, United States.

Brown, CL., Slight, SP., Husband, AK., Watson, NW., Bates, DW. (2015) A narrative literature review of medication-related clinical decision support: what issues are pertinent to its future development?, *The Royal Pharmaceutical Society Annual Conference, 13th- 14th September 2015,* Birmingham, England.

Brown, CL., Slight, SP., Husband, AK., Watson, NW., Bates, DW. (2015) A Narrative Review of Medication-Related Clinical Decision Support, *The 38th SGIM Annual Conference, 22nd- 25th April 2015,* Toronto, Canada.

Chapter 1

Medication Errors, Adverse Drug Events and the Role of Healthcare Information Technologies

1.1 Medication Errors and Adverse Drug Events

In the United Kingdom (UK), 9% of all reported incidents to the former National Patient Safety Agency (NPSA) in 2007 involved medicines.[1] The vast majority of medication incidents (96%, n=69,664) caused no or low patient harm; however, 100 cases of death or severe patient harm were also reported with a potentially devastating impact on their caregivers and relatives.[1] Hospital admissions as a result of patient injury from a medicine or lack of an intended medicine, also known as an adverse drug event (ADE), may incur large costs for the National Health Service (NHS), in addition to increased morbidity and mortality.[2] In the United States (US), the Institute of Medicine reported that between 44,000 and 98,000 people die in US hospitals each year due to potentially preventable medical errors.[3] More recent evidence suggests that as many as 400,000 premature deaths occur each year in the US due to preventable harm in hospitals.[4] In England, a Department of Health report published in 2018, estimated that 237 million medication errors occur each year, these were associated with causing 712 deaths and contributing to 1708 deaths.[5] A further systematic review found that 3.7% (range 1.4–15.4) of hospital admissions were drug-related and also preventable, demonstrating the global scale of the problem posed by medical and medication errors.[6]

Medication errors can occur when prescribing, dispensing, administering medications or monitoring patients. Prescribing errors are one of the most common types of medication error.[7] A systematic review of 65 studies conducted worldwide, found a median hospital inpatient prescription error rate of 7%, and notably that 50% of hospital admissions were affected by prescribing errors.[8] Indeed, many medication errors often go unreported, which means the true number may be far greater.[1, 9]

Medication errors that result in harm may be classified as either ADEs or potential ADEs (Figure 1).[10] Bates and colleagues found that almost a third of ADEs are preventable.[11] In particular, the most serious and life-threatening ADEs were more likely to be avoidable, and therefore could be targeted for intervention.[11] Such findings have led to the development of methods to reduce the numbers of preventable ADEs and improve patient safety.[4]
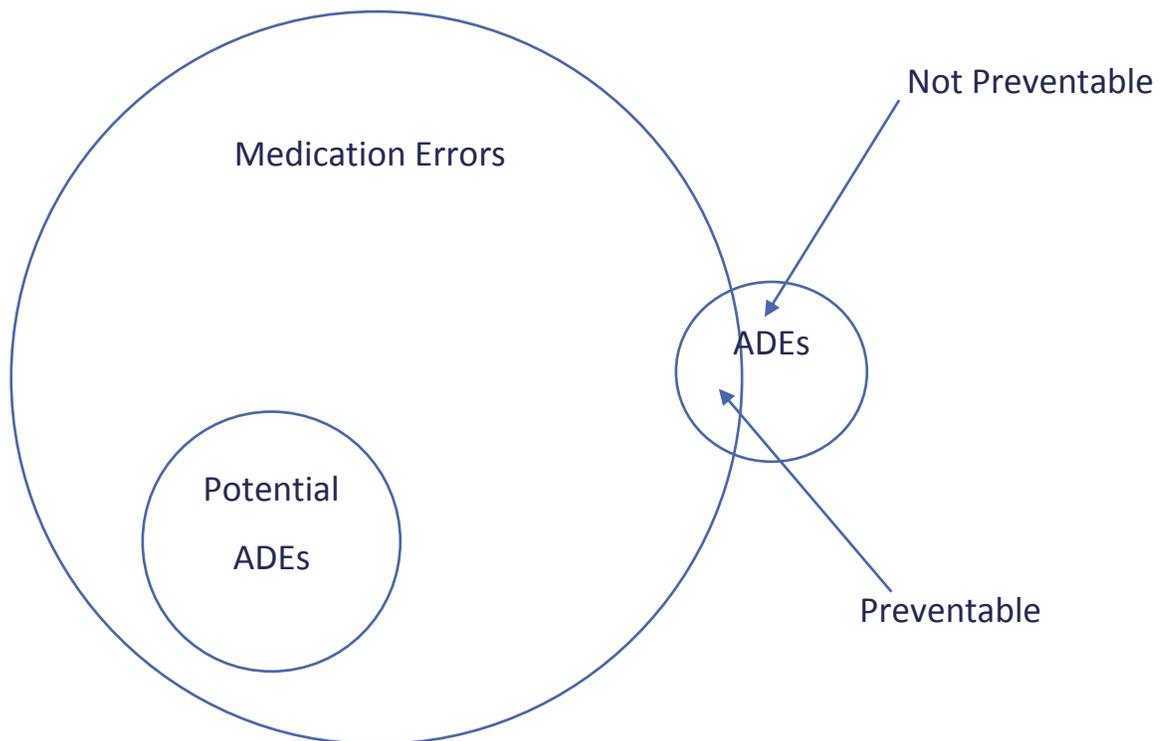
Figure 1: Relationship between medication errors and adverse drug events [10]

1.2 Causes of Errors

Human error can be considered in two ways; a person approach and a systems approach.[12] A person approach focuses error causation onto the individual who made the error, usually due to unsafe practice as a result of forgetfulness, inattention, negligence and/or recklessness.[12] A systems approach of error causation accepts and expects humans to make errors, which are not deliberate, and occur as a result of the conditions in which individuals work. This paradigm assumes that human conditions cannot be changed; however, the conditions in which humans work can be.[13] Crucially, when errors inevitably do occur the analysis will search not for who caused the error but why and how this error occurred, so as to introduce safeguarding measures and standardised processes.

Prescribing is a complex process;[3] the errors that occur can be defined as slips, lapses, mistakes and violations.[12] Slips occur when an action is not carried out as planned (*e.g.,* prescribing a medicine with the incorrect measurement units or for the wrong patient).[14, 15] Lapses also describe errors that occur when an action is not carried out as planned, but are more covert in nature (*e.g.,* forgetting to enter a piece of information on a prescription). Mistakes describe errors in which there is a failure in the judgement or process involved in the selection of an objective, regardless of whether the chosen process was carried out effectively (*e.g.,* failing to use reference sources or making a decision despite lacking knowledge about the patient). Violations describe errors that occur as a result of consciously ignoring known rules[16] (*e.g.,* writing 'U' instead of units).[12, 14]

The EQUIP study carried out a detailed investigation into the causes of prescribing errors by foundation medical trainees in hospital Trusts in North West England.[14] They found that lack of knowledge was a common cause in addition to slips and lapses.[14, 17] The design of the drug chart or electronic prescribing system may have also contributed to errors as the space to enter information was inadequate or poorly organised.[14] The PRACtICe study investigated the prevalence and causes of prescribing errors in General Practice and found that almost 5% (n=296/6048) of prescriptions included in the study were associated with a prescribing and/or monitoring error.[18] Slight *et al.* identified causes of prescribing errors in English General Practices, highlighting seven 'high-level' categories such as the prescriber, the patient, the team, the work environment, the task, the computer system, and the primary–secondary care

interface.[19] Additional factors, which may contribute to the occurrence of medication errors, include an increasingly complex medical practice (*e.g.,* an ageing population) with an increased risk of polypharmacy.[3, 4]

1.3 The Use of Information Technology in Health

Due to the high potential for errors throughout the medication use process (*i.e.,* during the prescribing, dispensing, administering and monitoring of patients), attention has now focused on the development of strategies to minimise these with a particular focus on information technology (IT). Electronic health records (EHRs) are one such example, the term used to describe a digital version of a patient's medical record that can be shared and accessed by different healthcare providers.[20] Other examples include: automated dispensing robots, electronic prescribing (ePrescribing), clinical decision support (CDS), patient barcode scanning, electronic administration, computerised lab results and prescription tracking systems (Figure 2). For the purposes of this thesis, the researcher will focus on interventions relating to prescribing.

Electronic Health Records

Summary Care records

Electronic medicines reconciliation (electronic records and linkage to prescribing system)

Electronic transfer of discharge documents

Prescribing

Electronic prescribing and pharmacist validation

Clinical decision support

Dispensing

Dispensing robots

Bar coding

Administration

Bar coding and patient wristband verification

Automated dispensing devices (medication storage in ward areas linked to patient EHR for nurse administration)

Electronic medication administration records

Monitoring

Computerised lab results

Clinical decision support

Figure 2: Automation in the medication process (adapted from Bates 2000) [21]

1.4 IT Interventions Related to Prescribing

ePrescribing is the process of ordering medicines electronically for a patient and has broadly been associated with reduced medication errors,[10, 22] increased prescription legibility and completeness,[23] improved patient safety, patient care and reduced healthcare costs.[22, 24] Terms related to ePrescribing include: Computerised Provider Order Entry (CPOE) to describe the electronic ordering of medications and other treatments *e.g.,* laboratory or procedures; Electronic Prescribing and Medication Administration (EPMA), which denotes a system with combined electronic ordering and administration functionality, and may include additional clinical support for example drug-allergy checks; and Clinical Decision Support (CDS), a term used to describe technology, which provides automated guidance and support at the point of prescribing, administration or validation. CDS is typically used alongside an electronic medication ordering system.

A systematic review by Ammenwerth *et al.* found 23 out of 25 studies reported a significant relative risk reduction (between 13% to 99%) in medication errors with ePrescribing.[25] This review also suggested that advanced forms of CDS were associated with a higher relative risk reduction than studies that investigated systems with minimal or no CDS.[25] A subsequent systematic review by Radley *et al.* found eight out of nine studies reported a pooled reduction in medication error rates of 48% after ePrescribing implementation.[26] Nuckols *et al.* similarly found that medication errors post-ePrescribing were approximately half as common (pooled RR= 0.46, 95% CI 0.35- 0.60) than when orders where written on paper charts in adult hospital-related acute care settings.[27] In this study the majority (n=12) of the 16 included articles included CDS. Ascertaining the effect of ePrescribing on ADEs compared to medication errors can be more difficult and has provided more variable results.[25] Ammenwerth *et al.* demonstrated a significant relative risk reduction in ADEs (between 30% to 84%) in four out of six studies; however, one study showed a non-significant increase of 9%.[25] Leung *et al.* also found that implementation of ePrescribing in five community hospitals in the US was associated with a reduction of over one third of all preventable ADEs; however, an increase in potential ADEs was also reported.[28] In their systematic review, Nuckols *et al.* also noted a reduction in preventable ADEs, which were half as common (pooled risk ratio (RR) = 0.47, 95% CI 0.31 to 0.71) post-ePrescribing compared to pre-ePrescribing when paper-orders were used.[27] Medication errors have also reduced following ePrescribing implementation in the paediatric setting;

however, a significant reduction in ADEs or mortality rates has yet to be shown.[29] The evidence suggests that ePrescribing and CDS systems have been strongly associated with a reduction in medication errors and to a slightly lesser extent ADEs. Furthermore, such technology can be used effectively in combination with other approaches such as a pharmacist review of the patient's medications and education interventions to reduce medication errors.[30] In particular, these systems can *'facilitate and enhance the communication of a prescription, aiding the choice, administration or supply of a medicine through decision support and provide a robust audit trail for the entire medicines use process'.*[31] The UK government has recognised these benefits and provided incentives for its use through the Integrated Digital Care Fund and the Safer Hospitals Safer Wards Fund.[32] This has contributed to an expansion in the use of such technology in hospitals, with the overall vision to 'raise our [NHS] game on health technology'.[33]

1.5 Chapter Summary

This chapter provides background information about the incidence and impact of medication errors and ADEs on the healthcare system, the causes of these, and finally the role of IT interventions in reducing errors and ADEs, focusing particularly on interventions that target the prescribing stage, such as ePrescribing and CDS. The next chapter will provide further details about the use of ePrescribing in the UK, the role of CDS, including recent advances and future work and finally discuss some of the challenges associated with these systems.

Chapter 2

Electronic Prescribing and Clinical Decision Support

2.1 Introduction

The aim of this chapter is to provide a comprehensive overview of two healthcare IT interventions (ePrescribing and CDS) that are used to prevent medication errors. These are traditionally targeted towards the prescribing stage, but can also play a role in the administration and monitoring stages of the medication process. A summary of the ePrescribing systems currently available in the UK is provided in this chapter, which is then followed by a detailed literature review of medication-related CDS.

2.2 The electronic systems currently available in the UK

As a result of government financial incentives such as the NHS Integrated Digital Care Fund, the Safer Hospitals Safer Wards Fund and the recent government recommendations to encourage increased productivity, UK hospitals have been encouraged to implement electronic systems.[34-36] In 2010, a questionnaire based survey of hospital and non-hospital attendees of the National ePrescribing Forum found that 82% of the 56 Trusts represented at the Forum were 'thinking of implementing' or 'currently implementing' an ePrescribing system.[37] In 2011 a postal questionnaire of acute NHS hospital Trusts in England found that 69% (n=70) of respondents had at least one form of ePrescribing system in use at their Trust. However, only one hospital used a single system across inpatient, discharge and outpatient prescribing and typically multiple different ePrescribing systems were used within the same organisation for specific processes (*e.g.,* discharge prescribing) or for certain clinical areas (*e.g.,* chemotherapy or critical care prescribing).[38] It is probable that the adoption rates of ePrescribing systems will increase further across secondary care in the coming years as their use becomes more common, similar to that seen in primary care whereby nearly all General Practices in the UK now have an EHR system in place.[39] The adoption and use of CPOE systems has also increased in the US, with a recent survey revealing that CPOE with CDS systems are now used in 95.6% of hospitals (based on a 29.8% response rate (n=392).[40] This has been largely driven by The Health

Information Technology for Economic and Clinical Health (HITECH) Act, which offered financial incentives to organisations that could demonstrate 'meaningful use' of (EHRs).[41] Australian government financial incentives have also been associated with increased uptake of computerised prescribing in primary care.[42]

In the UK, organisations are able to choose from a range of different systems that provide electronic prescribing functionality. These include home-grown systems, which have been designed and developed internally by a Trust such as the Prescribing Information and Communication System (PICS) developed by staff at University Hospitals Birmingham NHS Foundation Trust and commercial systems both developed nationally *e.g.,* 'Emis' and 'JAC EPMA' and internationally such as 'Cerner' and 'Epic'. Table 1 provides a list of current UK hospital ePrescribing and medication administration system suppliers that has been reproduced from the ePrescribing toolkit website.[43] Following the selection of a system, the organisation must consider where it will be implemented (*e.g.,* across all wards or limited to certain clinical specialities), how the system will be implemented, the training required, and the ongoing maintenance of the system, in addition to many other factors. In the US, issues surrounding process changes that impacted on prescribing and administration have been recognised as factors that have hindered adoption of new systems. These include: training requirements, staff resistance, poor design interface, product immaturity, considerable costs and the risk of new errors encountered during use of the system.[44, 45] Furthermore, organisations must also face the difficult challenge of deciding what features of their ePrescribing system will be 'switched on', and importantly whether CDS will be used and in what format.

Table 1: Suppliers of current hospital ePrescribing systems used in the UK (reproduced from ePrescribing Toolkit website)

Supplier	System	Date and country of origin	Website Address	Contact Details
Alert Life Sciences Computing	ALERT Prescription	1999, Portugal	http://www.alert-online.com	Head Office: Edifício Lake Towers Rua Daciano Baptista Marques, 245 4400-617 Vila Nova de Gaia Portugal Tel: +44 07525 262 853 Email: info.uk@alert-online.com
Allscripts	Sunrise clinicals	1995, US	http://uk.allscripts.com/	Battersea Studios 80 Silverthorne Road London, SW8 3HE +44 (0)20 7819 0444 And 15 Oxford Court, Manchester M2 3WQ,+0161 233 4999
Ascribe- Now Emis Health	Ascribe ePMA (Emis EP)	1984, UK	http://www.ascribe.com https://www.emishealth.com/products/EP/	Ascribe House, Brancker Street, Westhoughton Bolton, UK BL5 3JD Tel: +44(0)1942 852 400 Email: info@ascribe.com Emis Health Head Office Leeds - Rawdon House Rawdon HouseGreen Lane, Yeadon Leeds LS19 7BY Tel: 0113 380 3000
Cerner Corporation	Cerner ePrescribe (Millenium)	1979, US	http://www.cerner.com/	Cerner Limited 6th Floor, The Point 37 North Wharf Road London W2 1AF Tel: +44 (0) 20 7432 8100 Email: cerneruk@cerner.com
Civica	Paris EPR and Case Management	UK	https://www.civica.co.uk/health-and-social-care	Civica UK Ltd Station House Stamford New Road Altrincham Cheshire WA14 1EP Tel: +44 (0) 161 9415833

				Email: healthandsocialcare@civica.co.uk or sue.crawford@civica.co.uk
CSC	Lorenzo		http://www.csc.com/health_services/offerings/99982/103601-lorenzo	Contact via link: http://www.csc.com/contact_us/
CSC	Medchart		http://www.isofthealth.com/en-AU/Solutions/ANZ%20Hospitals%20and%20Clinics/Medication%20Management.aspx	Brian Hemming Tel: +44 (0) 129 527 4240 Email: brian.hemming@isofthealth.com
CSE (Servelec-Healthcare)	PICS	UK, 1998	http://www.servelec-healthcare.com	Servelec Healthcare The Straddle Victoria Quays SHEFFIELD S2 5SY United Kingdom Tel: +44 (0) 1246 437500 Email: Sales Email: sales@servelec-group.com Marketing Email: marketing@servelec-group.com HR - recruitment@servelec-group.com
ServelecHealthcare	RiO ePMA		http://www.servelec-healthcare.com/index.html	Servelec Healthcare The Straddle Victoria Quays SHEFFIELD S2 5SY United Kingdom Tel: +44 (0) 1246 437500 Email: Sales Email: sales@servelec-group.com Marketing Email: marketing@servelec-group.com HR - recruitment@servelec-group.com
Epic	EpicCare EMR	US, 1979	http://www.epic.com	1979 Milky Way Verona, Wisconsin 53593 Tel: 608-271-9000 Email: info@epic.com
JAC	JAC EPMA	UK,1983	http://jac.co.uk/complete_and_integrated_e_prescribing_medicines_administration_epma_/	JAC Computer Services1 Aurum Court Sylvan Way Basildon Essex SS15 6TH United Kingdom Tel: +44 (0) 1268 416348 Email: info@jac.co.uk

MEDITECH	Version 6.0	US, 1969	http://home.meditech.com/en/d/home/	One Northumberland Avenue, London, WC2N 5BW Tel: 0207 872 5583
Noema Life	Galileo Medication	1996, Italy		Registered Office: Monica House, St Augustines Road, Wisbech Cambs PE13 3AD Head Office: 2-3 St Johns Street Stamford Lincolnshire PE92DA (UK) Email: uk@noemalife.com Tel: 07875 088 981
QuadraMed Corporation	QCPA	1993, Canada	http://www.quadramed.com	QuadraMed Corporation, 12110 Sunset Hills Road, Suite 600 Reston, VA 20190 Tel: 703-709-2300
System C	Medway	UK, 1983	http://www.systemc.com	Medway EPR System C Healthcare Ltd +44 (0) 1622 691 616 enquire@systemc.com
TPP	SystmONE	UK, 1997	http://www.tpp-uk.com	TPP, Mill House Troy Road Leeds LS18 5TN Tel: +44 (0)113 2050080 Email: enquiries@tpp-uk.com

2.3 Medication-related Clinical Decision Support

Medication-related CDS provides guidance and decision-making support to clinicians, through the use of alerts and passive methods such as default drug dosages. Kuperman *et al.* categorised medication-related CDS functionalities as basic and advanced.[46] Basic medication-related CDS included drug-drug interaction (DDI) and drug-allergy checks, basic dosing guidance, duplicate therapy checks and formulary decision support. Advanced functionality included dosing support for renal insufficiency and older patients, guidance for medication-related laboratory testing, drug-pregnancy checking, and drug-disease contraindication checking. Medication-related CDS contributes to reduced morbidity,[47] improved prescribing practices,[47-50] facilitation of preventative care services,[47, 51] improved patient monitoring,[47, 51] reduced healthcare costs,[46, 52] and reduced ADE rates.[53] However, there is also evidence to suggest that many benefits of medication-related CDS have not been realised[54, 55] and clinicians may not always

be satisfied with CDS systems,[47] possibly due in part to poor consideration of environmental, organisational and individual requirements during the design and implementation stages.[53, 56]

Kuperman *et al.* published a review of the literature pertaining to medication-related CDS in 2007[46]. For this PhD the researcher reviewed the literature to summarise some of the more recent and important developments that have occurred with regards to medication-related CDS. The researcher also reflected on both exemplary practices and limitations of current approaches and made recommendations to inform future system development. This review has been published in the American Journal of Health-System Pharmacy*: Tolley, C, Slight, SP, Husband, A, Watson, NW, Bates, DW (2018) Improving Medication-Related Clinical Decision Support. American Journal of Health System Pharmacy (Appendix 1).[57]* The remainder of this chapter will describe the methods used for this literature review, the findings, and discuss some of the key recommendations in this area.

2.3.1 Methods

The researcher searched for articles across two large databases, Medline (Ovid) and Embase (Ovid), including various combinations of MeSH terms and keywords such as 'clinical decision support', 'computerized provider order entry' and 'electronic prescribing' with a date range of 2007 to 2014. Specific MeSH terms relevant to the five basic medication-related CDS functionalities: DDI checks (*e.g.,* Drug Interactions), drug allergy checks (*e.g.,* Drug Hypersensitivity), drug dosage support (*e.g.,* Dosage or Drug Dosage Calculations), drug duplication checks (*e.g.,* Drug duplication) and drug formulary support (*e.g.,* Formulary) were also used. The search strategy used for DDI checks can be found in *appendix 2*. Papers were included if they specifically discussed medication-related CDS functionality and their application; articles which did not primarily focus on medication-related CDS or were not concerned with the use of specific types of functionality were excluded. We limited our review to CDS linked with an ePrescribing system. The search included all publication types (*e.g.,* commentaries and non-peer reviewed material), all types of order entry systems (*e.g.,* commercial and home-grown), and all types of clinical setting (*e.g.,* primary care, hospital, ambulatory care) that were presented to all healthcare professionals (*e.g.,* doctors, nurses and pharmacists). Only English language papers were selected for review and duplicates were removed. Titles and abstracts were initially

screened to identify relevant papers, followed by the full text. The reference lists of included studies were also searched for other suitable papers, as well as a separate search conducted for pertinent articles by leading world experts, who have a strong publication history in the field. This was to ensure that papers describing important recent developments were included. The 'other citing articles function' was also used to retrieve additional studies. Papers were read and re-read, and key recurring themes and sub-themes related to each type of medication-related CDS were identified iteratively from the data.

2.3.2 Results

A total of 896 articles were identified across each of the five areas, of which 184 were considered relevant. This included 156 full text articles and 28 conference abstracts across the following functionalities: DDI checks: 78; drug-allergy checks: 20; drug-dose support: 55; drug-duplication checks: 11; and drug formulary support: 20. Each of the five medication-related CDS areas will be discussed in turn, before describing the importance of human factors principles in alert design.

2.3.2.1 DDI checking

Drug-Drug interactions occur when the action of one drug is affected by the presence of another and medication-related CDS can be used to warn clinicians about these.[58] However, to be successful, users must find DDI alerts clinically relevant and act on the information received, otherwise they can result in large numbers of unnecessary alerts, which the user becomes de-sensitised to, contributing to alert fatigue and the risk of missing important warnings. A range of commercially available order entry systems are available, which provide DDI CDS (*e.g.,* Epic, Meditech, Allscripts Sunrise and Cerner); there are also a range of different knowledge bases available to support these systems (*e.g.,* Medi-Span, First DataBank, Lexi-Comp). However, significant variability has been found in how DDI alerts are implemented and presented between organisations, even when the same ePrescribing system was used.[59] Three important aspects of DDI alerts will be discussed below including: (1) alert severity, (2) alert overrides, and (3) alert sensitivity and specificity.

Alert severity

Many medication-related CDS systems assign a severity level to DDI alerts. For example, level 1 *(contraindicated)* alerts indicate a very serious drug-drug interaction and require the clinician to either discontinue one of the drugs or cancel the order; level 2 alerts *(moderate to severe*) are less serious, but also require a response from the clinician, such as providing an override reason; level 3 *(mild to moderate)* alerts are the least serious and may appear as information only boxes on the screen[60] or even be suppressed by the organisation. Tiering alerts in this way has been associated with a significant reduction in override rates, where the user cancels or bypasses the alert, and can essentially eliminate overrides of level 1 alerts.[60] This reduction is likely to have improved patient safety, but further research is needed to show improvements in specific patient outcomes.[60] However, it is not clear whether displaying level 3 alerts is beneficial.

Assigning specific tiers to drug-drug interactions has been controversial, and there is poor agreement among reference sources regarding severity level. At the extremes, though, agreement is good, for example Phansalkar *et al.* created a list of 15 high priority drug pairs that should almost never be overridden.[61] This group also identified low severity DDIs that should be made non-interruptible in the medication-related CDS system in order to reduce alert fatigue.[62] However, most important drug-drug interactions fall into the level in between and sometimes should be overridden, as severity is greatly dependent on the individual patient and clinical context.[61] More work is needed to define which drug-drug interactions should be included as Level 2 alerts; a key effort should be to focus on making patient specific information usable by the medication-related CDS system so that alerts are only triggered when necessary and take into account human factors principles with the use of colour, placement and text.[56]

Alert overrides

High DDI alert override rates have been reported in the literature.[63, 64] Slight *et al.* evaluated the reasons why healthcare providers overrode these alerts *e.g.,* 'will monitor the patient' and what actions were taken as a consequence of overriding the alert. They found that these intended actions were only carried out in two thirds of cases, thus potentially exposing patients to harm.[64] Therefore, whilst improving design is important, it may also be necessary to address other elements that influence provider behaviour, such as workload and time constraints, which

may affect clinicians' ability to respond to alerts appropriately.[64] Nanji *et al.* found that class-class (*e.g.,* an ACE inhibitor prescribed with another ACE inhibitor*)* and drug-class (*e.g.,* a Hypnotic and benzodiazepine prescribed simultaneously) alerts were appropriately overridden more often than individual drug-drug alerts.[65] It was posed that clinicians may generally agree with alerts based on the larger categories, however make exceptions for individual drugs in these groups, where the benefit of the drug-drug combination outweighs the risk.[65] Studies using retrospective methods to assess the appropriateness of clinicians' overrides of DDI alerts may fail to record other interventions, such as additional patient counselling or a discussion between colleagues about the risks of a particular DDI. Further research should focus on such interventions made by clinicians as a result of the alert, which may not be captured in medication-related CDS systems.

Alert sensitivity and specificity

Low alert specificity (*i.e.,* lack of clinical relevance for an individual patient) and poor alert content were commonly cited reasons for high DDI alert override rates and alert fatigue.[66-68] Systems with high sensitivity (*i.e.,* ability to detect potential errors), but with low specificity can result in a large volume of potentially inappropriate alerts.[63, 69, 70] Such alerts are troublesome as they can lead to clinicians following erroneous alert recommendations or distrusting the system.[63, 71] Seidling and colleagues found that only 10% of DDI alerts were applicable in all circumstances, but by incorporating additional prescription information, such as dosage and route of administration into the decision-making algorithms, up to 25% of alerts could be appropriate.[72] This percentage could be further increased if laboratory results and other clinical parameters were included.[72] Duke and Bolchini developed the relatively new concept of context-aware DDI alerts, which focused on the potential outcome of the drug-drug interaction.[73] For example, if the outcome was bleeding, specific information such as prothrombin time and platelet count would be incorporated into the alert algorithm, and an alert would only be generated if laboratory markers were out of range. Although these prototype alerts were largely successful in a simulated environment,[73] adherence rates were found to be low (<20%) in routine clinical practice.[74] This may be due to the differences in alert design between the two studies, thus underscoring the importance of alert presentation.[73, 74]

2.3.2.2 Drug-Allergy Alerts

Drug allergy alerts are generated when a drug is prescribed that has been recorded as previously causing an adverse reaction. Some evidence suggests that drug-allergy alerts were accepted by clinicians more often than other types of medication-related CDS alerts,[75, 76] but high override rates have still been reported.[70] In this section, we concentrate on the importance of accurately recording allergy information in the patient's EHR and cross sensitivity checking.

Recording of accurate allergy information

The inclusion of inaccurate or incomplete allergy information in the EHR can lead to the production of clinically inappropriate alerts. Thirty-five percent of records in one study lacked allergy information, potentially exposing these patients to harm.[77] Computers require coded data in order to perform specific checks and thus may not detect errors in unstructured data (*e.g.,* free-text), or discourage prescribers from entering such information.[78-80] A lack of information about the type and severity of the allergic reaction also limits the usefulness of a system.[46, 79] Clinicians may fail to distinguish between drug allergies and intolerances,[46, 76] or be reluctant to remove information that is no longer relevant.[46, 79] One of the most common override reasons for drug-allergy alerts was 'patient took previously without allergic reaction'.[65, 81] Suppressing alerts that have been previously overridden for an individual patient [63, 82] and refining the categorisation of drug allergies, in a similar way to drug-drug interactions, may help to reduce the numbers of inappropriate drug-allergy alerts. However, a recent study also suggested exploring the reasons why clinicians did not update a patient's allergy information in the EHR, and work has been conducted in this area.[83] Further research is needed to ascertain how best to record allergy information and present the user with useful drug-allergy alerts. The alert could also provide an automatic link to the user to help them update the patient's allergy information if needed.[81]

Cross sensitivity checking

Drug-allergy algorithms vary in their ability to perform cross-sensitivity checks (sensitivity to a substance, which has a chemical structure similar to a known allergen) or checks on existing and newly prescribed medicines, when a new allergy is identified.[46] Alert specificity may be

improved through development of an alerting system based on chemical structure, which would aim to include only relevant drugs from a drug class or those with a high risk of cross-sensitivity.[70] This can be complicated and checks, which are overly inclusive, can be one of the main causes of false-positive drug-allergy warnings, thus knowledge bases must also incorporate clinical evidence on cross-reactivity.[82]

2.3.2.3 Drug Dose Support

Prescribing the wrong dose(s) of medicines can cause patient harm. Medication-related CDS can decrease the likelihood of these errors occurring by suggesting a drug dosage or utilising order sentences, which include drug name, form and dosage (thereby restricting the range of incorrect entries).[46, 84, 85] Medication-related CDS systems may perform clinical checks on existing or newly prescribed medicines[46] and with advanced functionality, take into account patient specific factors such as weight, co-morbidities, renal function and age, the latter two being the most important.[46, 86, 87]

Patient specific parameters

Kuperman *et al.* suggested that appropriate CDS dosing required integration of patient specific factors; however, recent evidence indicates drug-dose support is still underutilised [46, 88, 89] Missing data is often an issue; one study in the paediatric inpatient setting found patient weight was not recorded in 31% of cases, thus preventing many checks from being performed.[85] However, it may not be possible to accurately weigh a patient in certain situations, and therefore flexibility needs to be built into the system to accommodate this. Even when a patient's weight is recorded correctly doses may conflict based on different sources of evidence.[90, 91] System design and procedural issues may also unintentionally facilitate dose errors.[54] For example a 39-fold overdose of an antibiotic was administered to a patient when the total dose in milligrams was erroneously entered into a mg/kg dosage calculator.[92] The dose required to cause a maximum tolerated effect is dependent on patient specific factors like drug indication and laboratory results, thus the creation of a 'one rule fits all' standardised dose may not be appropriate for all patients.[93] The development of more advanced dosage support, which can calculate doses based on therapeutic drug levels or clinical parameters is therefore needed. However, as the range of exceptions to a dose range increases, so too does the number of rules

to review and maintain; this is an important consideration, particularly for smaller informatics teams. [85]

Drug administration

Some system calculated doses are often not easily administered, which can lead to clinicians altering doses inappropriately or difficulties measuring doses accurately. Drug-dosage support can recommend appropriately rounded doses to maximise usability and safety.[93] However, to realise their full potential, dosage recommendations should be combined with other factors like age, route of administration and patient preferences.[93] In some instances, the dose, calculated according to the patient's weight, may exceed the maximum daily dose based on the patient's age. Therefore, it is also important to consider not only the patient's age, but also their weight, relative to the specific drug indication.

Renal dosing and age-related dosing

Renal dosing alerts inform clinicians of appropriate doses for patients with impaired renal function. The timing of these alerts is important, as dosing suggestion(s) *before* the selection of a dose is obviously more beneficial to the prescriber than *after* both the drug and dose have been chosen.[56] Furthermore, the recommended dose should be relevant and specific. Sellier *et al.* were unable to demonstrate a significant reduction in inappropriate dosing, possibly due to the use of a 'dosage adjustment' table that displayed a range of values, in comparison to an exact recommended dose.[88] The inclusion of drug indication into decision-making algorithms is considered to be particularly important for age-related dosing alerts,[89] due to the wide range of doses for different conditions. The reasons for alert non-adherence, such as disease severity,[87] should also be explored and systems updated accordingly.

2.3.2.4 Drug Duplication Alerts

Medication-related CDS systems can generate drug duplication alerts when duplicates of the same medicinal product are prescribed, or drug therapy alerts for prescriptions of medicines with similar therapeutic effects. Some systems are not configured to generate alerts for different routes of the same medication (*e.g.,* intravenous and oral),[94] thus potentially exposing the patient to toxic drug levels. However, clinicians may have legitimate reasons for prescribing

duplicate drugs if, for example, different morning and night-time doses are required, or a topical and oral preparation are to be deliberately used in combination. This should be taken into consideration when designing the system, although one study reported an increase in duplication errors with ePrescribing and CDS implementation.[94] The authors noted how many patients might have received duplicate doses because the system failed to consider recently discontinued medications that might still be exerting a therapeutic effect.[94] An additional factor to consider when designing drug-duplication checks is the half-life of the medication(s) (*i.e.,* the time it takes for the concentration of a drug to half its initial value) and associated effect on concomitantly prescribed medications, and also whether the combination is intentional *e.g.,* tapering crossover of antipsychotics and antidepressants.[65, 76, 94] It has been suggested that intentional duplicate orders *e.g.,* an order for paracetamol for mild pain (when required) and for paracetamol/codeine to be taken if the pain is more severe (also when required) should be accompanied with an explanatory note for both the patient and/or nurse responsible for administering the drug product, so that they are both fully aware of when one should be administered over the other.[95] Medication-related CDS, which displays the drug indication, can be a useful guide for users. Although multiple healthcare providers should be able to prescribe for a single patient at any one time within an organisation, careful consideration should be given at the development stage as to how this can be conducted safely in order to avoid unnecessary duplicate orders or fragmented care.[96]

2.3.2.5 Drug Formulary Support

Drug formularies are lists of medications which have been approved for use by an organisation and offer benefits such as standardised prescribing and locally targeted therapies. Variable, incomplete and inaccurate electronic drug formularies may result in inappropriate drug formulary support.[97, 98] One study found that almost two thirds of reviewed drugs lacked information about drug restrictions after migration to an EHR, which could lead to clinicians deviating from hospital protocols.[99] Medication lists that do not distinguish between generic and brand formulations when prescribed by free-text may also contribute to the same drug being prescribed twice in both forms (due to a lack of prescriber knowledge).[80] Fischer and colleagues found a system that utilised colour coding to help distinguish between 'preferred' (green), 'non-preferred' (blue) and 'not approved'(red) drugs, helped increase prescriptions for lower cost medicines with potential for cost savings; notably, the system was not overly

restrictive as users were still able to select a non-preferred item; the colour simply guided the selection.[100]

2.3.2.6 Human Factors

Human factors is defined as the study of interrelationships between humans, the tools they use, and the environment in which they live and work.[101] Phansalkar *et al.* identified human factors principles that could be used to inform the design of CDS systems. These include alarm philosophy (presence of a reason for the alert and severity of consequences)[56], false alarms, placement, visibility, prioritisation, colour, learnability and confusability, textual information, habituation, mental models and proximity of task components being displayed.[56] Alert display has been found to strongly correlate with alert acceptance and should be considered when selecting a suitable CDS system.[67, 102, 103] Furthermore, greater consideration of how alerts should be presented to different users is clearly needed.[104]

2.3.3 Discussion

Medication-related CDS functionality is continually evolving, though there are many specific opportunities for improvement. Refining alert sensitivity and specificity, by including more patient-specific parameters, and greater consideration of human factors principles is important across all domains.

2.3.3.1 Standardisation: Benefits and Challenges

Alerts are produced when decision-making checks are performed on prescribed drugs. Information may be integrated into computerised algorithms from a variety of sources including: a knowledge base (which stores information about the drug *e.g.,* dosage and contraindications), clinical parameters (age and renal function), and from the EHR (medication history, co-morbidities) to assess prescription suitability. The extent to which organisations choose to utilise features varies widely between systems, for example, systems may assign different severity levels to particular drug interactions.[105] A lack of standardisation is potentially a source of user confusion and frustration, particularly for those working across multiple sites or clinical areas; it also makes determining an acceptable severity level and creating generalisable recommendations challenging.[55] Cornu *et al.* for example identified that out of a set of 15

previously defined level 1 DDI alerts, that should be generated in all EHRs were not always switched on across different systems in different countries.[106]The maintenance of an up-to-date knowledge base is also resource intensive; Johnson *et al.* estimated that a set of paediatric dosages would need to be fully reviewed at least every three years to reflect the addition of new therapies to the market.[93] Additionally, the evidence pertaining to the safety and efficacy of medications during use should be continually reviewed and the systems updated accordingly. Therefore, commercial knowledge vendors should consider the development of a nationalised knowledge base, which is managed centrally, similar to the Netherlands national drug database the 'G-Standard'.[107] Such a system would potentially require less input from individual organisations to review and update guidelines according to the latest evidence. In particular, McEvoy *et al.* recently suggested the creation of an officially approved, standardised knowledge base for DDIs in order to address the significant variation in DDI alert presentation observed in their study.[59] Payne *et al.* also recommended the consistent use of colour and terminology in how DDI alerts were presented. [104] However, such an initiative may be hindered by heterogeneity of vendors. Furthermore, studies have identified significant variation between vendors and organisational approaches to the implementation of medication-related CDS. [59, 105] Thus, there is a need for improved communication and standardisation of practices across systems and healthcare settings, where appropriate, to aid development of more universally applicable medication-related CDS.

Challenges to the development of standardised recommendations have been frequently reported and should be acknowledged. For example, producing dosage recommendations for drugs like aminoglycosides requires knowledge of patient specific information such as laboratory results and serum drug levels.[108] The sequence in which drugs are administered is also important, particularly for time dependent drug interactions. Determining whether a prescription is suitable according to hospital policies requires knowledge of the intended indication of the drug. Contextual factors such as the patient setting should also be considered. For example, alerts that advise patient monitoring are potentially superfluous in the hospital setting where some patients already receive intensive monitoring.[107] However, eliminating certain alerts across an entire care setting may be problematic. Seidling *et al.* described difficulties relating to the range of perceptions held by clinicians of variable experience and specialty.[107] The development of future medication-related CDS should therefore consider

both patient-specific and contextual information. Examples include customising alerts to individual clinical settings, certain clinicians (*e.g.,* doctor, nurse or pharmacist specific alerts) and encouraging local review of medication-related CDS rules.[109] This will also require the cooperation of commercial knowledge vendors and system suppliers to help facilitate such customisation. A difficulty for organisations is utilising and incorporating a range of clinical parameters into medication-related CDS decision-making algorithms from multiple stand-alone systems.[110] System developers should also aim to improve the interoperability between different standalone systems, *e.g.,* a prescribing system and a lab test result system, to facilitate the production of patient specific alerts. As such, selecting systems that integrate with the medication-related CDS system is important so that information can be utilised.

2.3.3.2 Human Factors Design

It is of central importance to carefully consider human factors design principles during the design and development of medication-related CDS systems.[56] A number of principles such as alarm philosophy, prioritisation, and learnability and confusability are absent in many systems.[103] In addition to improving alert relevance, it is also important that systems are built with an appreciation of environmental factors, including existing pressures and workflow.[111, 112] This is a challenge for commercial system developers, who may lack insight into how individual organisations or clinical areas function. Capturing users' experiences of medication-related CDS, such as the reasons for alert overrides and perceptions of usability, are very important if problems are to be exposed and refinements made to a system. One study found that the main reason nurses overrode recommended doses of insulin were due to concerns that the dose was set too high.[113] Such findings allow organisations to address clinicians' concerns through education and review of practice.[90, 113] System design should support users moving between tasks,[114] and any actions taken by users in response to medication-related CDS may highlight design flaws, which promote the use of workarounds.[105, 115] Investigating errors that occurred as a result of ePrescribing and medication-related CDS is also important and may highlight design flaws in the system.[116] For example, Horsky *et al.* identified a potassium chloride overdose that was partly caused by the provider's confusion between the parameters used for limiting the amount of medication delivered between drip (IV infusion) and IV bolus administration.[117] In another publication (*Appendix 3*), the researcher highlighted how drop-down menus, auto-population and a lack of CDS can also contribute to prescribing errors.[118]

As technology plays an increasingly important role in healthcare, organisations will need to consider the use of medication-related CDS alongside other systems, such as diagnostic support, which may put additional demands on clinicians. There is clearly a need for further research, particularly in sites with commercial systems, to identify the lessons learned from specific customisations and how these may be transferred to other sites.

2.4 Chapter Summary

This chapter has been divided into two sections; firstly the researcher has provided an overview of the use of ePrescribing systems, including a brief description of the types of systems currently available and factors that have influenced adoption rates in the UK. This was followed by a narrative literature review, which described the role of CDS and important recent developments that have been made in this area, over the last ten years, such as the importance of tiering drug interaction alerts, the need for more specific and sensitive recommendations and the significance of applying human factors design principles during the design and use of these systems. This review also highlighted areas in which there is scope for further research, for instance it raises the question of what is the best way to deliver CDS to clinicians. The issue of standardisation was also raised and the researcher discussed some of the advantages and disadvantages of standardising CDS systems. It was also clear from this review that there is a need for further research in sites that have implemented CDS systems in order to gather lessons learnt and share knowledge about these systems. Reports have also emerged that suggest that ePrescribing and CDS systems have been associated with some 'unintended adverse consequences' including 'new types' of errors. The following chapter will discuss some of the types and causes of prescribing errors generated when using ePrescribing and CDS systems.

Chapter 3

The Challenges of Electronic Prescribing and Clinical Decision Support Systems: Prescribing Errors

ePrescribing systems have been associated with unintended adverse consequences; in particular, use of these systems has been found to contribute to new types of prescribing errors.[115]The researcher conducted a systematic review to understand the different types and causes of errors that occur during the prescribing process when using ePrescribing systems and describes her findings in this chapter; this systematic review has been published: Clare L Brown, Helen L Mulcaster, Katherine L Triffitt, Dean F Sittig, Joan S Ash, Katie Reygate, Andrew K Husband, David W Bates, Sarah P Slight; *A systematic review of the types and causes of prescribing errors generated from using computerized provider order entry systems in primary and secondary care*, Journal of the American Medical Informatics Association, Volume 24, Issue 2, 1 March 2017, Pages 432–440, https://doi.org/10.1093/jamia/ocw119.[119] *(Appendix 3)*

3.1 Introduction

ePrescribing systems with CDS functionality have been shown to reduce the occurrence of prescribing errors.[22, 27, 51, 52] However, reports have also emerged that these systems (with or without CDS) have contributed to new types of errors in both primary and secondary care. [115, 120, 121] Some of these errors are potentially serious in nature, like a prescription for a 70 times overdose of diamorphine that occurred due to mis-selection of a dose from a drop down menu.[122] These errors have been frequently referred to as the 'unintended adverse consequences' of technology,[120, 123] a term which describes both the unexpected and undesirable nature of these events.[124]

Due to the relative newness of ePrescribing systems in many health care organisations, developers and users may be unaware of the generation or causes of these 'new' errors. A lack of consideration of human factors principles during the design stage has contributed to these issues emerging.[66, 125] Furthermore, despite certification requirements from the Office of the National Coordinator for Health Information Technology (an organisation tasked with supporting the adoption of healthcare IT solutions across the US) that required vendors to employ a user-

centred design process, a recent study reported that just over half of vendors studied actually employed usability staff and that use of this approach was variable at best. [126]

A study by Koppel *et al.* in 2005 sought to identify and quantify the role of CPOE in facilitating prescribing errors.[115] Since then, many more studies have used qualitative techniques to provide a rich understanding of the types and causes of these errors.[127] The researcher conducted a systematic review to understand the different types and causes of errors that occur during the prescribing process when using ePrescribing systems, and to make recommendations about how these systems could be improved.

3.2 Methods

Our review was conducted according to PRISMA guidelines;[128] each step is summarised below.

3.2.1 Eligibility criteria

Primary research studies that focused on prescribing errors associated with ePrescribing systems were eligible for inclusion. Studies that included qualitative data about the types and causes of these errors were included. Our search strategy covered the use of any type of ePrescribing system (*e.g.,* self-developed or commercial) in any clinical setting (*e.g.,* hospitals, outpatients and primary care). Quantitative data were not included because this review was aimed at describing the types and causes of ePrescribing related errors and not the frequency of errors. Studies published in peer-reviewed journals or conference proceedings between 1st January 2004 and 22nd June 2015 were eligible for inclusion. The search was restricted to English language publications. Editorials, commentaries, letters and opinion articles were excluded.

3.2.2 Information sources and search

Three large databases were searched: the Cumulative Index to Nursing and Allied Health Literature (CINAHL), Embase (via OVID) and Medline (via OVID). Appropriate search terms were developed and grouped into 'sets', specifically relating to 'electronic prescribing', 'computerised provider order entry', 'clinical decision support', 'electronic health records' and 'errors'. In each set, terms were combined with the 'OR' operator and sets were then combined with the 'AND' operator. Database functionality was used (where possible) to restrict the search to qualitative

studies. This search was conducted on the 22nd June 2015. *Appendix 4* details the search strategy conducted in Medline and Embase (Ovid).

3.2.3 Study selection

After duplicate articles were removed, three independent reviewers (CB, HM and KT) screened the titles to determine if the articles met the inclusion criteria. Two authors (CB and HM, or CB and KT) then independently reviewed all abstracts and full texts, with one author (CB) acting as a constant across all publications. Disagreements were resolved by discussion, with arbitration by a fourth additional reviewer (SPS), if necessary. The reason why a publication was rejected was also documented.

3.2.4 Data collection and analysis

A customised data extraction sheet was used by each of the three independent reviewers (CB, HM and KT) to extract specific details about each study's location, objectives, methods and key findings. A narrative synthesis of all eligible studies was undertaken. Papers were read and re-read by three authors (CB, KT and HT), and key recurring themes and sub-themes were identified iteratively from the data.

3.2.5 Bias Assessment

Due to the subjective nature of qualitative research, bias may occur. A critical analysis of included studies was performed using the Critical Appraisal Skills Programme (CASP) tool for qualitative research.[129] Mays and Pope have advocated the use of methodological triangulation (use of two or more methods) as a way of strengthening the research design and safeguarding the 'validity' of qualitative studies.[130] We also assessed the included studies for the use of methodological triangulation.

Identification

Records identified in the search:
(n = 1,185)

Screening

Number of titles screened:
(n = 1,185)

Duplicate articles and
Records excluded:
(n = 717)

Number of abstracts
screened:
(n = 468)

Records excluded:
(n=319)

Eligibility

Full-text articles assessed for
eligibility:
(n = 149)

Full-text articles excluded
(n=115) for the following
reasons:

- Lack of detail about CPOE related prescribing error(s): 57
- Not a primary research study: 36
- Quantitative study : 14
- Lack of detail about the causes of CPOE related prescribing error: 7
- Other: 1

Included

Studies included in
qualitative synthesis:
(n = 34)

Figure 3: Diagrammatic representation of the steps involved in the literature search

3.3 Results

A total of 1,185 publications were identified through the database search, with 1,036 excluded after removing duplicates and screening the titles and abstracts. On reviewing 149 full text articles, 115 were excluded; a total of 34 were therefore included in the final review. These comprised of 31 full text articles and 3 conference abstracts. Studies were conducted in the US (n=19), between the US and Canada (n=4), Canada (n=1), UK (n=4), Australia (n=2), Spain (n=1), Sweden (n=1), Netherlands (n=1) and Denmark (n=1). The bias assessment revealed three articles that did not use more than one method of data collection.[131-133] All articles were

included as they provided valuable insights. A table summarising the key findings of the included articles has been provided *(Appendix 5).*

A descriptive and narrative synthesis of the data was undertaken to understand the different types and causes of prescribing errors associated with ePrescribing systems, and eight key themes were identified and are discussed in detail below.

3.3.1 Computer Screen Display

The layout of the computer screen display affected how users viewed patient information. Displaying an incomplete list of a patient's medications on the computer screen was found by Horsky *et al.* to have contributed to an incident where a patient was prescribed an overdose of potassium chloride and subsequently developed severe hyperkalaemia.[117] Analysis of the same incident also revealed how intravenous (IV) medications were not displayed in the area of the screen where the patient's other medications were. This was likely to result in users missing or not considering these medicines when prescribing.[117] Similar issues have been raised in other studies by Wetterneck *et al.* and Koppel *et al.* who suggested that a failure to display all orders, including active, recently administered, PRN (when required) and STAT (immediate), may inhibit the user from reviewing the entirety of a patient's medications and result in duplicate doses being prescribed.[94, 115] The use of multiple screens, which require users to click through various parts of the ePrescribing system in order to access the necessary information, has been found to disrupt workflow and also led to users incorrectly entering information 'where it might fit' rather than where it was intended to go. The danger is that such information might not then be visible to other users and clinical safety checks may be bypassed.[120] Horsky *et al.* also found that similarly designed screens in one system had important functional differences *e.g.,* the parameter for limiting the amount of medication delivered was *time* dependent for drip (IV infusion) administration yet *dose* dependent for IV bolus administration, and subsequently could be easily confused by prescribers.[117] The ease of moving between different patients on an electronic system was also felt by Adelman *et al.* to have contributed to the placement of wrong patient orders, particularly if the prescriber's workflow had been interrupted.[134]

3.3.2 Drop-down menus and Auto-population

It is no surprise that selection errors associated with different drop down lists (*e.g.,* patient names, medication names, drug dosages, etc.) have been frequently reported.[19, 115, 134-136] Westbrook *et al.* examined the system related errors that occurred across two commercial CPOE systems and found numerous examples of selection errors. These included specific cases where the wrong route of a medication, *e.g.,* sodium chloride 0.9% infusion via the epidural route instead of the IV route were selected and the system did not restrict the list to only those potentially appropriate options.[137] Juxtaposition errors, whereby a medication listed before or after the desired medication was erroneously chosen, also resulted in orders being placed for drugs with an entirely different indication than what was intended.[120] One example included users' mis-selection of ethamsylate (a haemostatic agent) instead of ethambutol (an antibiotic) from a drug list.[135] Delays in system response time resulted in prescribers using 'multiple clicks' to select a drug item, which increased the risk of mis-selection.[19] Odukoya *et al.* highlighted that inadvertent 'mouse wheeling' (selecting an incorrect item by unknowingly scrolling past it) could also have contributed to incorrect orders being placed.[138] A range of prescribing errors have been attributed to the presence of auto-population functionality, whereby on entering the first few letters (or numbers) of a drug name (or dose), the system 'suggests' information that could be easily selected in error.[54, 138] Snyder *et al.* encountered a wrong drug order when "vir" was typed for the intended drug "Viread", and "efa" "vir" "enz", an alternative antiretroviral was suggested, as a prescribing option by the system autofill functionality and erroneously selected. [139]

3.3.3 Wording

The wording of the text used within ePrescribing systems has also been shown to contribute to prescribing errors. For example, in one study users misinterpreted the data label 'total volume', which they thought meant the total volume of dose that should be administered, rather than the system 'meaning' (*i.e.,* the total volume of an individual bag of fluid).[117] Horsky *et al.* described these misinterpretations as a 'user-design mismatch'.[117] Another example included a dose of 20 mg written as 0020.000 MG, which could be misinterpreted due to the additional zeros presented.[140] One study that explored ePrescribing related prescribing errors in a General Practice setting found that users had difficulty finding items or knowing the specific

wording that would allow them to select certain drugs, *e.g.,* a particular type of insulin from a pick-list.[19]

3.3.4 Default Settings

Overly restrictive default settings have been associated with a number of ePrescribing related prescribing errors. Prescribers may simply fail to change a default order sentence containing drug name, form and dosage, or a default time presented by the system, thus resulting in a patient receiving the wrong dose, missing a dose or receiving it at an unintended time.[115, 135, 137] Koppel *et al.* found that some 'late in the day orders', where the prescriber had intended the patient to receive the drug on the same day, were delayed until the next day, with potential consequences for the patient.[115] If the drug combination carbidopa/levodopa (Sinemet®), for example, is not administered at the appropriate time, then a patient with Parkinson's disease can experience adverse motor-symptoms. Similarly, duplicate dose errors have been reported, with a patient being administered a night-time dose of the antiviral efavirenz (Sustiva®) and an inappropriate second dose the following morning because the system automatically defaulted to a 09:00am daily dose.[139] Lack of knowledge about the default stop dates and times of certain medications can also lead to errors.[117] Some systems combine default order sentences as part of an order set to make it easier to prescribe a group of medicines, *e.g.* for post-surgical analgesia. Doctors interviewed in one study described an instance where a non-steroidal anti-inflammatory drug was 'hidden' in an order set and inappropriately prescribed to an asthmatic patient.[135] Default settings for some medicines used in certain clinical specialities therefore may not be appropriate due to the range of prescribing options, which are dependent on patient specific factors. For example, the dose of azathioprine (an immunosuppressant) is often dependent on the patient's weight, indication, laboratory results and thiopurine S-methyltransferase (TPMT) activity, thus a list of suggested doses may be confusing unless the system is able to guide the user by taking these other patient factors into consideration.

3.3.5 Non-intuitive ordering or information transmission

Inflexible or complex ordering processes made entering some orders particularly difficult and resulted in users employing workarounds to avoid some of the issues encountered. These included selecting a default drug order sentence (*e.g.,* give twice daily) and adding a contradictory free-text comment that advises the nurse to administer something different (*e.g.,*

give three times daily). Unfamiliar abbreviations were also entered in free-text boxes, which in turn were open to misinterpretation by different users.[140] Zhan *et al.* found that a system failed to recognise the abbreviation 'TID' (take three times a day) and therefore did not record this order.[141] Odukoya *et al.* described an example of confusing directions written in free-text: *"take a half tablet and there will be a period and then it will say take two tablets…"*.[142] Users employed workarounds to prescribe complex prescriptions, which were generally very difficult to write electronically, such as tapering courses of prednisolone.[105] 'Copy and paste' functionality, which is designed to save users time, was also found to unintentionally give rise to the generation of incorrect orders.[131] Wentzer *et al.* also observed instances where medications, which had been previously prescribed on a prior hospital admission and stopped, were transferred to the new admission as an 'active' medication and inappropriately continued.[143]

3.3.5.1 Interoperability Issues

One study described the compatibility issues between a prescribing system and a community pharmacy system, which related to a failure of one system to correctly interpret the terminology, possibly due to a lack of standardised codes in requests, *e.g.,* 'magnesium citrate' or 'mag. citrate'. Certain requests (*e.g.,* mag. citrate) were translated incorrectly by the community pharmacy system once received, and led to prescriptions being generated for the inappropriate drug name, quantity package size, and patient name.[138] Similarly, Nanji *et al.* identified important information that was omitted from prescriptions electronically ordered from either inpatient or outpatient prescribing systems and received by a community pharmacy system. It was felt that this was related to a mismatch between the text-box size in the prescribing system (on which the order was originally placed) and the pharmacy system (on which the order was received), thus leading to certain information being missed or not communicated.[144]

3.3.6 Repeat prescriptions and automated processes

An important difference between handwritten and electronic prescriptions is the ease with which a repeat electronic prescription can be generated with a few simple clicks.[136] This is clearly more efficient for users, but there is a downside. There have been cases where pharmacists have picked up prescription errors in the past, but the original prescriptions (which

contained the error) were not updated in the system and subsequently repeated.[138] [144]These erroneous electronic prescriptions may be harder to detect as one study participant describes: *"But if there's a black and white typed document that includes nonsense, it is harder to recognise it and it's more easily overlooked or assumed to be correct…".*[136]

3.3.7 Users work processes

Inappropriate work processes, for example, entering all of a patient's medicines in batches at the end of a ward round on the ePrescribing system, pose safety risks.[110] Issues can arise around whether a prescriber can correctly recall potentially large lists of medications.[143] Delays in entering information can result in clinicians, who were not present on the ward round, being unable to immediately utilise such information for their own decision making.[110] Similarly, an inconvenient log-in process can give rise to users working under other colleagues' log-ins, which has both legal and professional implications.[145] Wentzer *et al.* found that some doctors would login to the ePrescribing system and allow a nurse to work under their account, thus the person whose ID the system recognised as making an order was not actually the *true* prescriber of that order.[143]

3.3.8 CDS systems

As previously discussed, the consequences of over-alerting and alert fatigue are well described in the literature.[54, 55] However, a lack of appropriate safeguards may also prevent prescribing errors from being detected, particularly if users have wrongly assumed that their orders are being checked. For example, Schiff *et al.* identified one hospital site that was unaware that their CDS alerts had been switched off following a system update.[105] This study also identified many CDS systems that did not offer sufficient protection against many common errors.[105] Wetterneck *et al.* found that orders for different forms of the same medication *e.g.,* metoprolol 25mg tablets (oral) and metoprolol 5mg IV, were not identified as potential duplicates when prescribed together, and therefore did not generate an alert.[94] Underutilisation of CDS functionality was reported by Khajouei *et al.* who found that a button prescribers needed to click to perform a dosage calculation was not clearly displayed, and therefore prescribers continued to manually calculate doses, which increased the risk of potential human errors.[145] CDS systems have also provided users with erroneous information, such as inappropriate dosages

that do not take into account patient specific factors (*e.g.,* reduced renal function)[54] or orders based on outdated drug information.[105]

3.4 Discussion

This evaluation describes the types and causes of prescribing errors associated with ePrescribing systems, specifically identifying themes from qualitative studies. The eight key areas were: computer screen display; drop-down menus and autopopulation; wording; default settings; non-intuitive ordering or information transmission; repeat prescriptions and automated processes; users work processes; and CDS alerting. All of these relate closely to human factors and user-centred design. Table 2 provides a summary of the key themes, associated issues and recommendations, and whether the error could be classified (predominantly) as system related, user related or both.

Table 2: Key themes, associated issues and recommendations

Main Error Facilitator	Key Themes	Specific Issues	Recommendations
System related	Computer Screen Display	• Incomplete Display.[94, 115, 117] • Navigation between multiple Screens.[120, 134] • Confusing data labels.[117]	• All medications (oral, intravenous etc.) and all statuses (active and discontinued etc.) should be clearly displayed in one area if possible. • The naming of data labels should be unambiguous. • Post-implementation testing is crucial to identify any issues. • Consistent use of colour and design throughout the system.
System related	Drop-down Menus and Auto-population	• Mis-selection errors:[19, 115, 120, 134-138] o Similar named medications or patients located next to each other o Orders listed above or below the intended order o Delays in the system response time and use of 'multiple clicks' o Scrolling onto the wrong order • Erroneous suggestions of medications, doses or patients.[54, 138, 139]	• Avoid overly long lists of patient's names or medications. • Distinction between 'look-alike-sound-alike' medications using tall man lettering, colour or bold font. • Indication based CDS alerts. • Improved sensitivity and specificity of CDS functions.
System related	Wording	• Confusion between the system's wording and user's interpretation of that meaning.[19, 117] • Unnecessary 'trailing zeros' *i.e.,*0020.000mg instead of 20mg.[140]	• Pre and post-evaluation of user's normal workflow and practice to ensure user-informed design. • Enable local customisation according to local practice and terminology.
System related & User related	Default Settings	• User related • Failure to change suggested default settings.[115, 135, 137, 139] • Lack of knowledge about default settings.[117] • System related • Orders hidden within pre-defined order sentences and order sets.[135]	• User education and training about complex prescribing functions and challenges that may be encountered with using the system. • Development of more sophisticated, patient specific pre-defined order sentences and order sets.
System related	Non-intuitive ordering or information transmission	• Lack of standardised terminology.[138, 140-142] • Interoperability issues.[138, 144]	• Facilitate local customisation to incorporate local terminology. • Consistent use of key terms between systems. • Addressing interoperability issues between standalone systems, particularly at the transmission of information stage.
System related	Repeat Prescriptions and Automated Processes	• Repetition of previously corrected errors.[136, 138, 144] • Reduced visibility of computerised errors.[136]	• Introduce additional checks into the prescribing process. • User training and education about the risks of using workarounds.
User related	User's Work Processes	• Batch order entry [110, 143] • Users working under another colleague's log-in. [143, 145]	• User education and training about the risks of using workarounds.
System related and user related	CDS Systems	**User related** • Lack of knowledge about the CDS checks that are performed.[105] **System related** • Inconsistent and insufficient use of CDS to safeguard against errors. [94, 105] • Poor CDS design.[145] • Erroneous suggestions due to issues with, CDS sensitivity, specificity and accuracy of information.[54, 105]	• Education and training about the systems functions (and lack of) • Use of CDS, where a clinical need has been identified. • Refining the sensitivity and specificity of CDS

This systematic review described errors relating to the way information was displayed on the computer screens.[110, 117] One simple solution might be to organise the screen layout such that all medications (including both oral, IV, rectal and vaginal etc.) are listed in one area, with minimal navigation required. Additionally, data labels should be clear to the user and guide them to separate areas where further specific information can be obtained.[125, 146] System developers and implementers should consider the potential for a 'user-design mismatch' and the importance of designing the system according to the users' workflow and the terminology that they use.[117] Indeed, as many issues may not be identified until after system implementation, there is a clear need for post-implementation testing to ensure that these systems are working as intended.[110] There may also be additional organisational benefits of improving the design of such systems; Chan *et al.* found that a well-designed ePrescribing system could also possibly reduce the need for training.[147] In this study, no participants requested assistance when ordering a medicine using the user-centred design format compared to over one third of participants requesting assistance on a 'standard' ePrescribing test system.[147] Horsky *et al.* demonstrated the potential for confusion amongst users who used functions that were visually very similar on the order screen but behaved differently *e.g.,* the function to calculate total dose for infusion or IV bolus orders.[117] Design tools, such as colour and language, should be applied consistently throughout a system (and possibly all systems) to prevent users misinterpreting information during the prescribing process and further research is needed to establish what colours, language and terminologies are effective.[125]

The design of ePrescribing systems is a critical consideration. Drop-down menus can provide a list of drug dosing options in ascending or descending order, so as to make it easier for prescribers to find exactly what they are looking for. However, long lists of medications, particularly those listed alphabetically, with names which look-alike or sound-alike are prone to selection errors. Westbrook *et al.* found that 43% of system-related errors were due to selection errors, which led the authors to conclude that reducing the opportunities for users to 'select' items from lists during the course of prescribing may reduce ePrescribing related errors. [137] This should be weighed against the potential consequences of prescribers entering erroneous doses in free-text, and the additional time this manual entry of information may take.[125] Tall man lettering has been used to help users distinguish between similar drug names such as

hydrOXYzine and hydrALAzine.[148] There is some limited evidence from experimental studies to support its use more generally;[149] however, there is currently a lack of robust studies relating specifically to ePrescribing systems and the effect of tall man lettering in certain users, such as those with dyslexia.[148] Galanter *et al.* showed that indication-based alerts can help intercept wrong drug and wrong patient orders (commonly encountered with selection and autofill entry errors), by halting the prescriber's workflow and allowing them to self-correct the order.[150] Due to the potential burden of excessive CDS alerting, the use of indication alerts for high-risk, look-alike-sound-alike, drug pairs should be considered.[151]

The issues identified in this review pertaining to default doses have been supported in the quantitative literature. Eslami *et al.* found that 86% (n=113) of orders placed for two aminoglycoside antibiotics (gentamycin and tobramycin) using the suggested default dose were associated with an overdose, compared to only 53% (n=66) cases when the default dose was not selected.[152] This default dose was based on an average sized adult with normal renal function, and thus poses the question about whether such default doses are well placed in certain clinical specialities where patients are more likely to have parameters that frequently fluctuate outside of normal limits (*e.g.* Intensive Care Unit (ICU) or a nephrology ward).[152] Order sets can standardise prescribing and improve adherence to guidelines. However, we found that certain items were inadvertently prescribed for some patients (via an order set) as they were 'hidden' among a list of medications, which included both suitable and unsuitable items. Bobb *et al.* suggested that order sets should be more patient specific, presenting only relevant recommendations *e.g.,* a non-penicillin drug for a penicillin allergic patient as first-line treatment.[153] They also recommended that individual items within an order are linked, so that they are updated in unison. For instance, if an order set contains supportive therapy (*e.g.,* a proton pump inhibitor) for an indicated medication (*e.g.,* corticosteroid), the supportive therapy should be ceased when the indicated medicine is discontinued.[153]

We found that free-text orders were commonly used as a method of bypassing system requirements or CDS alerts. A quantitative study conducted by Palchuk *et al.* found discrepancies between the information contained in the structured and free-text fields in 16% (n=470) of electronic prescriptions.[154] System developers should consider the development of more sophisticated CDS, which can perform checks on free-text orders.[154] Furthermore, the frequent use of free-text options by users may suggest a lack of suitable structured functions.

Dhavle *et al.* found that many free-text comments encountered in their study could be avoided by using an updated version of the ePrescribing system, which incorporated additional structured fields.[155] Developers should address this need by providing prescribing options, such as a tapering course of steroids or alternate day dosing, as part of ongoing system optimisation and development,[156] in addition to accelerating the rate at which new functionality reaches users.[155] Certain ePrescribing systems are unable to accommodate prescriptions for drugs given via multiple routes (for example providing an oral and rectal option so the nurse can decide how to give the medication depending on the clinical context); this suggests a possible lack of understanding and consideration of actual prescribing and administration practices that would need to be addressed. Ongoing testing and evaluation of systems (and any customisations made) is needed in order to optimise and enhance ePrescribing systems following initial implementation.[157]

CDS has undoubtedly contributed to a reduction in errors and has huge potential to further improve safety in the future.[47] However, as this review has found, there is still much to be done to improve the safety of these systems. Schiff *et al.* discovered that only 26.6% (n=95) of a sample of erroneous test-orders generated warnings thus allowing many potentially harmful orders to be placed.[105] Additionally, there was considerable variability in the way organisations implemented CDS functionality and the ability of different systems to warn clinicians about errors,[105] which may confuse users who work across multiple sites. Wright *et al.* also found examples of malfunctioning CDS, resulting in a failure to generate warnings when needed or the production of unnecessary alerts. Such malfunctions were due to software upgrades, code changes, accidental alteration of CDS rules, and faults with external systems.[158] Customisation is crucial for organisations striving to achieve safer patient care following ePrescribing implementation. One study found that even a small 5% increase in the Leapfrog score (an evaluation tool, which tests CPOE systems ability to safeguard against erroneous test orders) was associated with a significant reduction in preventable adverse drug events.[159] Thus, organisations should be reassured of the benefits of customising their system to include a range of CDS checks. Perhaps one of the most crucial developments will be the production of more patient specific and better worded alerts to reduce the impact of alert fatigue and erroneous suggestions.[69] A recently published study by Slight *et al.* found that some alerts (*e.g.,* duplicate drug alerts) contained confusing wording and did not explicitly

describe the error present, (*e.g., "(the drug) already exists . . . under the selected assessment"*, highlighting the need to improve system usability.[151]

Human factors and user-centred design is key across all of these eight areas and should be prioritised when developing these systems. There is a need to thoroughly evaluate ePrescribing related incidents so as to better understand system failings, using various (or a combination of different) approaches [160] such as failure mode and effect analysis,[161] visual and cognitive walkthrough evaluation,[117] and usability evaluation techniques (including semi-structured interviews and observations).[162] Phansalkar *et al.* created a list of such principles specific to the design of CDS alerts to prevent confusion and maximise their impact.[56] Russ *et al.* saw a significant reduction in prescribing errors when they redesigned CDS alerts according to human factors principles;[163] this was attributed to improved visibility of text, more logical organisation of information and more informative alerts.

This systematic review has provided strong insights into the key structural design elements associated with ePrescribing related prescribing errors. However, the review only reported what has been published in the peer-reviewed literature and there may be unpublished work that could also provide valuable insights. Another possible limitation is that this review spans over ten years and it is possible that some system vendors may be currently working on or have already addressed some of the issues highlighted. [115] For instance, all six EHRs evaluated in one study displayed patient identifiers on the top of the computer screen throughout the prescribing process, thus helping to reduce wrong patient errors. [140] Finally, there may also have been a publication bias towards studies that reported more positive findings and consequently the number of different types of ePrescribing related prescribing errors may be much higher. However, the findings of this review highlight the need for further research into uncovering these specific types of errors and for the establishment of a national reporting database where these types of errors should be logged and addressed (both by vendors and by local customisation teams). [127, 164]

3.5 Chapter Summary

This chapter is based on a systematic review, which identified eight key areas that have been associated with ePrescribing related prescribing errors. All of these relate closely to human

factors and user-centred design. The design and layout of the computer screen display should be carefully considered. Drop-down menus should be designed with safeguards to prevent the occurrence of selection errors. Local customisation and development of more sophisticated CDS, which can perform checks on free-text and provide users with adequate prescribing functions, is clearly needed. Developers must aim to improve the specificity, sensitivity and usability of these systems in light of the recent research in this area. The following chapter specifically focuses on the literature that describes the factors that have contributed to medication errors that have been made when using ePrescribing and CDS systems in paediatrics.

Chapter 4

Medication errors made when using ePrescribing systems in paediatrics

Paediatric patients are particularly vulnerable to medication errors. The researcher conducted a systematic review to identify and understand the factors that contribute to medication errors when using ePrescribing and CDS systems in paediatrics, and describes her findings in this chapter. This systematic review has been published: Clare L Tolley, Niamh E Forde, Katherine L Coffey, Dean F Sittig, Joan S Ash, Andrew K Husband, David W Bates, Sarah P Slight; *Factors contributing to medication errors made when using computerized order entry in paediatrics: a systematic review,* Journal of the American Medical Informatics Association, ocx124, https://doi.org/10.1093/jamia/ocx124 *(Appendix 6).* [165]

4.1 Introduction

Medication errors in the paediatric population are common; one study estimated that a child experiences an out-of-hospital medication error every eight minutes in the US [166] An earlier study found that as many as 27% of paediatric inpatient medication orders contain an error.[167] The potential ADE rate for children has been found to be three times higher than that of the rate for adults.[168] Paediatric patients are particularly vulnerable to medication errors; their physiology is continuously changing and their ability to tolerate errors is limited.[169] There is also a lack of paediatric-specific medications currently available on the market. This leads to medications being used 'off label' (outside the terms of license *i.e.,* for an unapproved clinical use) more often than in adults. Also, as physicians often need to calculate doses based on a child's weight or body surface area, the opportunity for calculation errors is potentially greater than in adults.[170]

ePrescribing and CDS have been associated with a reduction in medication errors[25, 26, 171] not only in the adult population but also in paediatrics.[172] The introduction of an ePrescribing system in one tertiary care paediatric hospital was associated with a 40% reduction in the

medication error rate (Rate Ratio 0.93 95% CI 0.76-1.13, pre CPOE and 0.60 95% CI 0.48-0.74 post CPOE).[172] However, we also know that the introduction of these systems can introduce new types of error.[115, 119] A systematic review conducted by Reckmann *et al.* identified four studies that explored the quantitative effects of ePrescribing systems on medication errors in paediatric hospital inpatients.[173] All four of these studies demonstrated a reduction in errors, but further details about those errors that were generated when using ePrescribing were beyond the scope of this review.[173] Another review by Ghaleb *et al.* identified dosing errors (often those associated with 10-fold overdoses) as the most common medication error type in paediatrics;[174] however, this review did not focus on errors that occurred with the use of an ePrescribing system.[174]

In a previous systematic review, the researcher identified eight factors that contributed to the occurrence of ePrescribing related prescribing errors.[119] These included issues with the computer screen display, drop-down menus and auto-population, wording, default settings, non-intuitive or inflexible ordering, repeat prescriptions and automated processes, users' work processes and CDS systems. However, the design and functionality of CPOE systems in the paediatric setting may differ substantially from those used in the adult setting, with paediatric specific functionality or completely specialised paediatric systems.[175] Furthermore, current ePrescribing systems have been criticised for 'falling short' of providing recommended characteristics, for example, availability of the patient's current medication history, alerts and reminders, prescribing practice feedback and others,[176] so the researcher was eager to identify and understand the factors that contribute to medication errors associated with their use, and provide recommendations on how these systems could be improved.

4.2 Methods

Our review was conducted according to PRISMA guidelines and registered with PROSPERO: PCRD42016039984.[128]

4.2.1 Eligibility criteria

Quantitative and qualitative primary research studies that focused on medication errors (*e.g.,* before and after comparative studies, evaluations of error reports, and failure modes and effect analyses) associated with ePrescribing systems with and without CDS used in the paediatric

population (<18 years or population defined by the study as 'paediatric'), which included data about the types and/or causes of these errors, were eligible for inclusion. Our search strategy covered the use of all types of ePrescribing systems (*e.g.,* home-grown or commercial) in any type of clinical setting (*e.g.,* hospitals, outpatients and primary care). Studies published in peer-reviewed journals or conference proceedings were included. The timeframe of the search was not restricted. Only articles published in the English language were included. Editorials, commentaries, letters and opinion articles were excluded.

4.2.2 Information sources and search

Three large databases were searched on 3rd May 2016: Cumulative Index to Nursing and Allied Health Literature (CINAHL) (1982 - present), Embase (via OVID) (1974 - present) and Medline (via OVID) (1946 - present). Appropriate search terms were developed and grouped into 'sets', specifically relating to 'computerised provider order entry', 'clinical decision support', 'electronic health records (EHR)' and 'errors'. In each set, terms were combined with the 'OR' operator and sets were then combined with the 'AND' operator. *Appendix 7* includes the search strategy conducted in Embase (Ovid).

4.2.3 Study selection

After duplicate articles were removed, three independent reviewers (CLT, NF and KC) screened the titles to determine if the articles met the inclusion criteria. Two authors (CLT and NF, or CLT and KC) then independently reviewed all abstracts and full texts, with one author (CLT) acting as a constant across all publications. Disagreements were resolved by discussion with a fourth reviewer (SPS), if necessary. The reason why a publication was rejected was also documented.

4.2.4 Data collection and analysis

We developed a customised data extraction sheet to be used by each of the three reviewers (CLT, NF and KC) to independently extract specific details about each study's location, objectives, methods and key findings. This included both qualitative and quantitative data related to the occurrence of medication errors that were made when using ePrescribing systems in paediatrics and the factors (*e.g.,* system design) that contributed to such errors occurring. A narrative synthesis of all eligible studies was undertaken. Papers were read and re-read by three authors

(CLT, NF and KC), and key recurring themes and sub-themes were identified iteratively from the data, using an inductive approach. This involved summarising the raw data into a brief format, deriving clear links in these data, and developing a thematic framework into which main-themes and sub-themes could be grouped.[177] This framework was validated through peer de-briefing with a further author (SPS).[178] Sub-themes that lacked sufficient detail in the included studies were noted in *Appendix 8* and Table 3: Key factors, specific issues and recommendations; hence, these sub-themes were not discussed further in this review. Authors from two papers were contacted by email to obtain further information.[179, 180] The data pertaining to the specific causes of the error was of particular interest to meet our objectives.

4.2.5 Risk of Bias (Quality) Assessment

It was anticipated that the included studies would be too heterogeneous (*e.g.,* a range of pre-post intervention studies with a qualitative element, surveys, and studies using failure modes and effects analysis to identify risk in a system) to allow for systematic application of a quality assessment tool, therefore quality assessment was not conducted. All scientific studies were included; this included large quantitative retrospective reviews of error reports, or before and after studies using chart review methods to identify errors, and in-depth failure modes and effect causality analysis about a stage of a process at one organisation. We included all studies due to their potential to add valuable insight in this area. The examples included were intended to be illustrative of the point(s) being made and provided specific details about the causes of errors to aid the reader's understanding.

Identification

Articles identified in the search

(n = 419)

(Medline n=167, Embase n=144, CINAHL n=108)

Screening

Number of titles screened:

(n=419)

Duplicate articles removed

(n= 134) and titles (n= 58) excluded:

(n = 192)

Number of abstracts screened:

Records excluded:

(n = 95)

Eligibility

Full-text articles assessed for eligibility:

(n = 132)

Full-text articles excluded (n=85) for the following reasons:

- Lack of detail about types and causes of CPOE related errors (n=31)
- Study not conducted in paediatrics or paediatric data not distinguishable (n=12)
- Not CPOE (n=15)
- Not original, peer reviewed research (n=26)
- Focus on reporting of errors (n=1)

Included

Studies included in qualitative synthesis:

(n = 47)

Figure 4: Diagrammatic representation of the steps involved in the literature search

4.3 Results

Our search identified a total of 419 papers, duplicates were removed. Articles were removed at the title (n=58), abstract (n=95) and full-text stage (n=85). Forty-seven articles (44 full texts and three conference abstracts, two of which had corresponding full text papers based on the same study data[181, 182]), were included in this review. Studies were conducted in the US (n=29), UK (n=4), Canada (n=2), Iran (n=2), Netherlands (n=2), Sweden (n=2), with the remaining countries (France, Israel, Singapore, Spain and Taiwan) publishing just one paper each. Of these, 38 used quantitative methods, 6 used mixed-methods (with two papers reporting on the same data), and 3 used either failure modes and effect analysis or qualitative methods. The qualitative data ranged from larger studies that performed a qualitative analysis of 613 overridden CDS alerts to smaller studies that interviewed prescribers on a 17-bed ward.[63, 183] Non-English language papers were excluded. Further details about the included studies, methods used and key findings of relevance can be found in *Appendix 8*.

We identified five key factors that contributed to errors with the use of an ePrescribing system in paediatrics: (1) lack of drug dosing alerts, (2) the generation of inappropriate drug dosing alerts, (3) inappropriate drug duplication alerts, (4) drop down menu selection errors, and (5) system design. We describe each of these in turn using examples that the authors felt best illustrated the issues being discussed. Out of the 47 individual articles, 40 had subthemes which were included in the five overarching themes. Other areas that lacked sufficient detail such as documentation discrepancies or omission of information on the electronic order have not been discussed in depth within this review as it was not possible to explore such topics fully.

4.3.1 Lack of drug dosing alerts

Doses were often calculated according to a patient's weight with one minimum and maximum dose value recorded on the system. Stultz *et al.* noted how these minimum and maximum doses were based on a specific drug indication (*e.g.,* lupus nephritis) and sometimes lacked drug dosing alerts for other indications (*e.g.,* status asthmaticus).[184] For example, an alert was not presented for an overdose of methylprednisolone prescribed at 2mg/kg (instead of 1mg/kg) intravenously every 6 hours for status asthmaticus, as the maximum dose for lupus nephritis was 30 mg/kg/day. In other words, the maximum dosing alert was only triggered if the highest

possible dose on the system was exceeded, regardless of the indication for which the drug was prescribed.[184] Studies also highlighted how users were not alerted to calculation errors because the system did not include any automated dosing support functionality.[185] Similarly, Jani *et al.* noted how the system used in their study failed to alert the prescriber to an overdose of prednisolone (49.5mg instead of 15mg). In this example, the user had mistakenly requested all doses of a titrating dose (15 mg once a day for 2 days, 10 mg once a day for 2 days, etc.) to start on the same day. This was reported as quite a significant incident as this patient could have potentially received almost two weeks of treatment in one day,[186] which could have resulted in increased serum glucose concentrations, effects on mental state and cardiovascular issues.[38] Crucially, there was no active dosing support in this ePrescribing system, such as minimum and maximum dose checks, or indication based dosing suggestions.[186]

4.3.2 The generation of inappropriate drug dosing alerts

The existence of minimum and maximum dose values on the ePrescribing system also led to inappropriate alerts being generated. Scharnweber *et al.* described how amoxicillin/clavulanate (an antibiotic) was calculated according to a patient's weight, with one minimum (26 mg/kg) and one maximum (875mg) dose value recorded on the system.[187] The authors explained how, when a 36kg patient was prescribed 900mg BID (twice daily), two contradictory and inappropriate alerts were generated: an under-dose alert because the dose (900mg) was under the system calculated dose of 936mg (based on the 26mg/kg calculation), and an overdose alert because the dose (900mg) exceed the system's maximum dose of 875mg.[187] Scharnweber *et al.* also found that a large number (n=500) of under-dosing alerts were inappropriately generated for enteral erythromycin orders, which users ignored. Investigation of these events revealed that the dosing rule logic had not been updated to reflect the more recent use of erythromycin as a pro-kinetic agent (rather than as an antibiotic), which used a lower dose.[187] The risk here was that users inappropriately prescribed erythromycin at the higher dose with the increased likelihood of gastrointestinal side effects. Kirkendall *et al.* evaluated a set of vendor-supplied dosing rules against the most common dose from a selection of gold standard paediatric dosing sources (*e.g., Harriet Lane Handbook (19th edition)*, *PDR.net (Physician's Desk Reference), Epocrates Online, Micromedex and Lexi-Comp Online (CCHMC formulary),* and found that they only exactly matched in 55.1% of cases.[91] It is possible that this could have contributed to the generation of inappropriate drug dosing alerts and/or providers ignoring these alerts. Kirk *et al.*

found that providers did not trust the computer calculated doses and often manually adjusted these doses, which were associated with paracetamol over and under-dosing.[188]

Missing or out-of-date patient information within the ePrescribing system may have also contributed to either a lack of appropriate alerts or the generation of dosing errors. Killelea *et al.* found that 31.1% (n=17,051) of medication orders lacked a bodyweight for the patient in the system and, although age could be used in some cases to determine the dose, the authors reported that over 4,500 orders could not utilise the available CDS because this information was missing.[85] Similarly, Kazemi *et al.* discovered that prescribers in a neonatal intensive care unit rarely updated the dose or frequency according to the patient's age on the system and so ran the risk of under-dosing the patient for a period of their admission.[183] Kazemi *et al.* posed that some users ignored alerts because they could not understand the recommended dose, particularly for more complex doses such as those that were based on renal function, where the calculation method was not clear.[183]

4.3.3 Inappropriate drug duplication alerts

Jani *et al.* found that drug duplication alerts were not generated when the same medication was ordered via a different drug name, strength or formulation in a system, even though this would have resulted in a duplicate order.[189] For example, a patient who was prescribed prednisolone 12.5 mg once a day as part of a clinical trial, was also prescribed a second dose of prednisolone 12.5 mg once a day (out-with the trial), because the system did not generate an alert for this 'non-trial' dose.[189] Mille *et al.* however encountered false-positive drug duplication alerts because the system had failed to consider either the route of administration or the dates over which the drugs were administered.[63] For example, an inappropriate alert was generated when nalbuphine (opioid) was prescribed over the time period 20th-25th December, when there was an existing prescription for codeine (opioid) over the time period 1st-5th December in the system. Similarly, inappropriate drug duplication alerts were generated when a duplicate prescription of salbutamol was made but by different routes (*e.g.,* inhaled and intravenously), although this would not have resulted in any significant interaction.[63] A 'not advised' warning was also encountered when medications (that contained alcohol) were prescribed for a child with a sedative agent.[63] However, the authors explained how these alerts were felt to be of

little value to the health care provider because no suitable alternative product existed, increasing the likelihood of alert fatigue.[63]

4.3.4 Drop down menu selection errors

Selection errors with drop down menus were relatively common. Walsh *et al.* reviewed 352 inpatient ward admissions and discovered that almost 20% (20/107) of the medication errors identified in their study were computer related; the majority (n=9) of these were due to drop-down menu errors *e.g.,* mis-selection of an option alphabetically listed above or below the intended order.[156] Four of these mis-selections were classed as serious errors, as they had the potential to cause substantial harm to the patient. Ceftriaxone, an antibiotic may be prescribed in mg or g (maximum dose of 4g in adults and children >12 years).[190] However, Walsh *et al.* reported a 1,000x overdose of this antibiotic (900g selected rather than 900mg) as a result of a drop-down menu selection error; luckily, this error was intercepted before reaching the patient, although such a dose would have been very difficult to administer (*i.e.,* the nurse would have to administer 900 x 1g ceftriaxone vials).[156]

Caruso *et al.* also encountered serious dose errors, which they felt were due to user mis-selections; such as 100-1,000 under and overdoses of paracetamol and some antibiotics.[191] They posed that this was because of the ease with which the 'ml (milliliter)' option could be selected from a drop down menu, instead of 'mg' (milligram).[191] Kazemi *et al.* suggested that non-patient specific drop-down menus and default order-sentences may fail to achieve the same success in the neonatal paediatric population compared to the adult population, owing to the huge range of doses that may be appropriate for a paediatric patient based on their individual age or weight.[183] The use of non-standardised concentrations in a system, for example mg/5ml and mg/1ml for different drugs, *e.g.,* amoxicillin 400mg/5ml and fluconazole 10mg/ml was also found to be more commonly associated with calculation errors than non-liquid dosage forms in one study. The route associated with different concentrations for oral and intravenous preparations was also unclear on the system and felt by the authors to have contributed to errors.[192] Holdsworth *et al.* reported how the suggested doses from a drop-down menu of a paediatric dosing table for opioid based analgesics were based on the lower end of the standard dose.[180] This was intentional as the expectation was that providers would choose the lower dose and increase according to the patient's pain levels. However, the system did not prompt

users to adjust the dose after first ordering and thus patients were often under-dosed.[180] Cochran *et al.* posed that drop-down menu selection errors of a pre-defined order sentence were potentially more likely to reach the patient as the pharmacist would be less likely to detect an inadvertent mis-selection of an incorrect option.[193] Errors involving mis-selection of a patient name or wrong drug product were also reported.[186, 189, 194]

4.3.5 Inappropriate System Design

Users resorted to including free-text dosing instructions in some systems due to a lack of available dosing options. For example, Cochran *et al.* found that a physician was forced to select '1 drop by mouth' from a drop-down menu and add the free-text instruction '1 dropper daily', because the desired option did not exist on the system.[193] Discrepancies between the free-text comment and electronic orders were felt to be particularly common in paediatrics because 'non-standard' doses, volumes, or directions for oral liquids, drops or topical preparations were more frequently used.[193] Nelson *et al.* also found that omission errors were more likely to occur when users entered an order in free-text, and thus missed important prescription information (*e.g.,* directions for 'when required' usage).[195]

Walsh *et al.* highlighted how easy it was to make a prescribing error while using order set system functionality. The authors described how one provider had mistakenly selected all items from an order set, thus prescribing a duplicate dose of a hepatitis B vaccine for a patient who had already received the vaccination at another hospital.[156] This order set also contributed to erroneous orders of the hepatitis B vaccine being placed for premature infants weighing less than 2kg. Kim *et al.* also found an increase (n=14/1253 pre-ePrescribing to 67/1112 post-ePrescribing) in the risk of medication orders that did not match the chemotherapy treatment plan after ePrescribing was implemented.[196] Secondly, new or experimental drugs did not always appear on the pre-defined drug menu, thus had to be entered manually.[196]

4.4 Discussion

We identified five key factors that contribute to errors with the use of ePrescribing systems in the paediatric population: (1) lack of drug dosing alerts, which failed to detect calculation errors, (2) the generation of inappropriate dosing alerts, such as warnings based on the incorrect drug indication, (3) inappropriate drug duplication alerts, as a result of the system failing to consider

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factors such as the route of administration or the dates over which the drugs were administered, (4) drop down menu selection errors that resulted in large overdoses of antibiotics being ordered, and (5) system design issues, such as a lack of suitable dosing options for a particular drug. Below the researcher will comment on each of the five factors and summarise recommendations made by prior authors that we deem especially useful. Table 3 provides an overview of the key factors, specific issues and recommendations arising from this review. Table 4 provides specific information about some of the pros and cons associated with these recommendations.

Table 3: Key factors, specific issues and recommendations

Key Factor	Specific Issues	Example	Recommendations
Lack of drug dosing alerts	• Absence of indication specific dose ranges thus dose errors were not identified.[184, 197, 198] • Lack of dosing-support functionality in use.[179, 182, 185, 186, 192, 199-202] • Lack of support for dosing calculations. [203-206]	• Failure to alert when an overdose of methylprednisolone was prescribed at 2mg/kg (instead of 1mg/kg) intravenously every 6 hours for status asthmaticus, as the maximum dose for lupus nephritis was 30 mg/kg/day.[184]	• Encourage use of dosing support. • Indication-based dosing alerts. • Indication based order sentences. • Documentation of relevant historical data within the system *e.g.,* vaccination history and radiation exposure.[207]
Generation of inappropriate drug dosing alerts	• Ambiguous dose ranges that had conflicting over-dose and under-dose alerts for certain patient weights.[187] • Inappropriate under-dose alerts due to a failure to update drug dosing logic to reflect most recent doses for certain medications.[187] • Lack of agreement between vendor-supplied dosing rules and suggested doses from gold-standard courses.[91] • Lack of trust in computer calculated doses.[188] • Absence/ lack of information e.g. patient weight entered into the system preventing utilisation of available CDS.[85, 183, 208] • Failure to display calculation method for suggested doses.[183] • Failure to consider normal dose rounding procedures.[209] • Alert overrides.[63, 188, 208, 210]	• Inappropriate generation of under-dosing alerts for enteral erythromycin orders, because the dosing logic did not include the more recent use of erythromycin as an anti-motility agent (rather than as an antibiotic), which used a lower dose.[187]	• Enforce entry of patient weight before dosing medications.[85] • Suggest system prompts up to date values for certain parameters *e.g.,* age or weight when reasonable.[85] • Systems should provide condition specific growth charts and age-appropriate references throughout a patient's care.[211] • Standardised fixed dose order sets for most high-risk drugs.[179] • Dose rounding.[207] • Use of most up-to-date patient data.[207]
Inappropriate drug duplication alerts	• False- positive and false negative alerts because of a lack of consideration of medication name, strength, route and time of administration, formulation or reasonable alternatives.[63, 189]	• Inappropriate drug duplication alerts were generated when salbutamol was prescribed twice but by different routes (*e.g.,* inhaled and intravenously), although this would not have resulted in any significant interaction.[63]	• Context specific alerts.

Drop-down menu selection errors	• Miss-selecting from a list.[183, 186, 189, 194, 210, 212, 213] • Alphabetical listing and juxtaposition selection errors.[156, 191, 214] • Presence of non-standardised concentrations in the system contributing to calculation errors.[192] • Non- patient specific drop down menus and suggested order-sentences prone to error.[183] • Presented doses did not include the full range of clinical possibilities or provide sufficient guidance related to titrating doses.[180] • Selection errors possibly less able to detect as potentially gives a reasonable order, though inappropriate for a specific patient.[193]	• A 1,000x overdose of the antibiotic ceftriaxone (900g selected rather than 900mg) was prescribed as a result of a drop-down menu selection error.[156]	• Avoidance of long drop-down menus.[215] • Ensure list is up to date and comprehensive based on the organisation's usual prescribing habits. • Indication based dosing CDS (order sentences or required information prior to dose selection).[150, 216] • Interventions to reduce wrong patient selection errors e.g., non-sequential identification numbers, identification re-entry or distinct naming convention.[134, 217]
Inappropriate System Design	• Error prone free-text orders as a result of insufficient structured dosing options.[193, 195, 218-220] • Select all functionality on an order set resulted in drug-duplication errors.[156] • Failure to link protocols with ePrescribing system.[196] • Manual order entry (rather than selecting an option from an order sentence) because drug dictionary had not been updated to reflect current formulary. • Inappropriate system design which impacts on clinical workflow.[221-224] • Omission errors, potentially due to a lack of mandatory fields or pre-populated information.[225-227]	• A physician was forced to inappropriately select '1 drop by mouth' from a drop-down menu and add the free-text instruction '1 dropper daily', because the desired option did not exist on the system.[193]	• Use of standardised units throughout a patient's care or automated conversion between units.[228] • Evaluation of normal work processes and effects of intervention on 'down-stream' effects of ePrescribing.[221] • Limit use of select all functionality where feasible.[156] • Linkage of data e.g., maternal and child data with EHR.[207] • Use of mandatory fields.[229]

Table 4: Major Recommendation: Pros and Cons

Major Recommendations: Pros and Cons		
Major Recommendation	**Pros**	**Cons**
Provision of dosing support with calculations based on body weight.	Likely to improve safety and reduce medication errors.	Improving the sensitivity and specificity of any dosing support may require additional information such as the drug indication.
Mandate entry of patient's weight.	Important for dosage calculations. Potential for time savings due to reduced calls from pharmacy.	Potential to disrupt the user's workflow and impact on satisfaction.
Availability of treatment protocols, age specific growth charts and reference ranges at the point of ordering.	Supports safer prescribing and may reduce medication errors.	Possibility of overloading the clinician with information if these tools are not incorporated correctly.
Provide details of the calculation method for dosing suggestions generated by the system.	Users can understand the way doses were calculated by the system, which may provide users with a learning opportunity.	May impact on the user's workflow unless system designed in such a way that the calculation method is available on request.
Evaluation of dosing alert overrides.	Provide insight into potential system design flaws *e.g.,* inappropriate dosing limits.	May require additional tools and resources to undertake such evaluations.
Greater standardisation of paediatric doses and units.	Potential to improve medication safety.	Difficult to reach consensus on specific paediatric doses and possible variability in expert opinion.
Providers to document a patient's exposure to an agent(s) over time and vaccination history.	Complete records that will help to better inform future prescribing decisions.	Increased documentation load for users.
Prompt provider to enter the drug indication.	Potential to improve the specificity of the system's decision support and reduce selection errors.	Increased documentation load for users, and certain information may not be readily available.
Use of non-sequential naming format and ID re-entry for children born from multiple births.	Reduce wrong patient errors.	Increase the time needed to enter the patient's ID.
Pre-implementation assessment of wards and clinical workflow, and pre-emptive considerations of potential challenges and risks to inform the system design.	Anticipate, prevent or minimise risks as a result of workflow changes.	Resources and expertise to perform robust pre-assessment. Opportunities to modify the system design will depend on the commercial system vendor.

4.4.1 Dosing support and Recommendations

Dose errors have been commonly reported both in adults and paediatrics, before and after implementation of an ePrescribing system.[105, 115, 168, 185, 186, 188, 230] Indeed Schiff *et al.* found that 'ordered wrong dose or strength errors' were one of the most common error codes (alongside missing or incorrect directions) that they assigned when reviewing 10,060 US MEDMARX error reports.[105] Dean-Franklin *et al.* also found dose errors following the implementation of a closed-loop electronic prescribing and administration system in a UK hospital site; however, wrong administration route and omission errors were

found to be more common than dose errors.[231] Paediatric patients are particularly prone to dosing errors, as calculations are often needed to determine the amount of drug to be given (weight based dosing), thus increasing the opportunity for human error. A key feature of ePrescribing systems is the ability to support prescribers by helping to calculate a dose based on a patient's weight, body surface area, and drug indication, particularly for high risk drugs.[30] However, this review highlighted how there was a lack of CDS tools, such as weight-based dosing calculators, in many of the ePrescribing systems studied.[179, 185, 199, 200] Even if such tools existed, some systems were missing key information *e.g.,* a patient weight, which prevented certain checks from being carried out[85]. Furthermore, missing data can increase the need for prescribers to be contacted at a later date to add this information.[232] Thus, we propose that system developers should mandate the entry of certain key pieces of information, *e.g.,* an up-to-date weight estimate before ordering a particular medicine or prompt providers to provide an up-to-date value when needed.[85] However, increasing the documentation load for clinicians may also be undesirable and reduce satisfaction with the system.[233] Furthermore, where possible, treatment protocols should be incorporated into the ePrescribing system to guide the physician to reduce errors at the ordering stage due to slips and lapses.[196] Lehmann suggested that systems must provide clinicians with condition specific growth charts, age appropriate reference ranges, and decision support throughout the patient's care.[30]

Available dosing tools were also in need of some improvements. The setting of minimum and maximum doses on the system for example was responsible for the generation of inappropriate dosing alerts.[91, 184, 198] Non-specific or erroneous alerts can contribute to alert fatigue and high override rates, which have been well discussed in the literature.[54, 55, 76] Therefore, understanding the reasons behind alert overrides is vital to ensure that systems are designed appropriately. In particular, the dosing support did not always consider the drug indication that the medication was prescribed for.[187] Scharnweber *et al.* suggested that at the very least CDS dose limits should include the lowest and highest ranges to ensure that all potential errors would be identified,[187] and the researcher would also add that this should be tailored to the drug indication where possible. Kazemi *et al.* also suggested that the ePrescribing system should display the calculation method used in the alert logic to help improve transparency and reduce any confusion about how the dosing suggestion was derived. It was also noted that this might improve alert acceptance.[183]

The lack of standardised and approved paediatric drug doses, which in turn were not or could not be incorporated into ePrescribing and CDS systems, contributed to some systems failing to detect certain 10-fold under-dosing errors. It would therefore be reasonable to suggest greater standardisation of paediatric doses in the future.[179] However, there are important challenges here in developing standardised guidelines for the paediatric population, such as the use of drugs 'off-label' or a lack of agreement between clinicians.[179] Doherty *et al.* suggested the creation of standardised fixed-dose order sets that were based on a patient's weight, specifically focusing on the most high-risk drugs.[179] Condren *et al.* also suggested that measurement units be standardised to prevent miss-calculation associated errors.[192] Standardised units therefore should be used consistently in ePrescribing systems across all aspects of a patient's care *e.g.,* a patient's weight should be documented in kilograms and grams rather than pounds and ounces. ePrescribing systems again could guide the user to enter information in the desired format or automatically convert or display the units in a particular format depending on the user's preference *e.g.,* the patient may prefer to discuss their weight in pounds and ounces.[228] Patterson *et al.* suggested that it should be possible for providers to document a patient's cumulative radiation exposure and vaccination history, including those given at different organisations, to ensure a comprehensive history is available on the ePrescribing system.[28]

4.4.2 Drop-down menus

ePrescribing systems can assist clinicians by providing drop down menus with a list of pre-defined order sentences to choose from (including the drug, dose and route), thereby reducing the risk of placing an erroneous free-text order.[46] However, as reported in our previous review, these drop-down menus can be error-prone and can contribute to wrong patient, medication, and dose errors, amongst others being selected.[119] Furthermore, it has been suggested that these tools, which have been successfully employed in systems used in the adult population, may fail to achieve the same results in paediatrics.[183] There are a wide range of doses that may be appropriate for a child depending on their age, weight, comorbidities, and the drug indication. Compared to adults where doses are usually available as a full dosage form unit *e.g.,* '1 tablet' or '1 ampoule', in paediatrics the dose may consist of a portion of the full dosage form *e.g.,* one tenth of a tablet.[183] Khajouei and Jaspers suggested that long drop-down menus, which require the user to scroll up and down, should be avoided as these can be non-user friendly and may contribute to selection errors.[215] Furthermore, the absence of a necessary dosing option from a drop down menu could result

in the user adding contradictory free-text comments[193], which may be confusing and lead to patient harm.[154]

As the drug dose is closely related to the drug indication, it would seem reasonable for systems to prompt the provider to enter this information first, from which indication-specific doses could then be selected.[216] Schiff *et al.* and Galanter *et al.* have pointed out that such an approach would not only help the provider select the correct dose but also potentially reduce mis-selection errors.[150, 216] Furthermore, if information about the drug indication was available to other healthcare professionals, such as pharmacists, they could also perform a more detailed clinical check of that order and potentially be better equipped to identify errors.[216] The use of indication-specific order sentences should be considered, so the provider is clear about the specific indication that the order sentence relates to. This could represent a relatively easy adjustment to the system and is relevant to both adult and paediatric patients.

Lowry *et al.* also suggested that non-sequential identification numbers be assigned to newborns in the same hospital, particularly if the child was from a multiple birth (*e.g.,* twins or triplets), to prevent the risk of patient name mis-selection.[217] Adelman *et al.* found that interventions such as the introduction of ID re-entry (providers must verify the patient's identity by re-entering the patient's initials and sex before they have access to the order entry screen), and use of a distinct naming convention (replacing non-distinct naming of newborns *e.g.,* 'baby-girl' with a naming format that includes the mother's name and birth number *e.g.,* '1firstnamesexsurname' '2firstnamesexsurname' etc.), particularly for multiple births in a Neonatal Intensive Care Unit setting may significantly reduce the risk of wrong patient errors.[134]

4.4.3 System design and workflow considerations

There is a clear need for systems to be developed with an understanding of normal work processes and prescribing habits in both the adult and paediatric settings.[234] Han *et al.* for example, reported an increase in mortality after an ePrescribing system was implemented in a paediatric setting.[221] Workflow changes may not be associated with a specific type of error, but rather impact the entire medication process, making it more error prone. Prior to system implementation, a team of physicians and nurses worked together to stabilise critically unwell patients; post-implementation, one physician was required to remain on the computer and enter orders, and was therefore not available at the bedside.[221] Such

examples demonstrate the down–stream effects of ePrescribing implementation, especially when poorly done, on the entire work process and emphasise the need to evaluate the impact of such systems on patient outcomes *e.g.,* ADEs and mortality, including those that measure users' experiences and system usability.

Walsh *et al.* suggested that the 'select all' option within an order set should be removed.[156] According to the authors, this could possibly reduce the risk of patients receiving inappropriate or duplicate doses of a medication with prescribers 'selecting all' and not taking the time to check the appropriateness of each drug in the order set. Further research is clearly needed to determine what the positive and negative impact would be of removing such an option, particularly if it increased the time taken to prescribe.

A key finding from this review was that included studies mostly focused on the effect of ePrescribing on medication error rates and ADEs, and only a handful fully explored the errors encountered during use of these systems. A lack of such information limits the ability of organisations and system developers to recognise and address system flaws, and thus further research is needed to understand the wide range of issues that are specific to a paediatric population. In 2015, the Agency for Healthcare Research and Quality produced an updated list of high priority recommendations for the formatting of paediatric EHR systems.[207] Examples include linkage of maternal and child data within the EHR, age specific decision support, rounding of administrable doses and re-prescribing medications, based on the most recent information about the patient (*e.g.,* increasing the dose on a re-fill prescription according to the patient's age). Studies have highlighted the importance of designing and customising systems according to human factors design principles[56] and incorporating recommendations from those with expertise in human factors.[28] These must be considered by system developers, healthcare organisations, practitioners and other key stakeholders involved in the use of healthcare information technology in paediatrics.[39]

Previous literature reviews have mainly focused on the rates of medication errors following the introduction of an ePrescribing system in paediatrics.[29, 173, 235] This review adds to the literature by outlining specific factors that have contributed to medication errors arising or persisting with the use of such systems, specifically in paediatrics. It is important for system developers and healthcare organisations to not only be aware of these areas, but also help address them to improve patient safety. There are a number of recommendations that the researcher believes would be valuable to make in both the adult and paediatric

settings *e.g.,* the use of indication specific doses and use of standardised units within the system; it is important that these changes are independently validated in both settings. There are limitations to this review; firstly, although the researcher searched for papers across three large databases she only reported the findings from the published literature and therefore may have failed to capture relevant content within unpublished work. Secondly, owing to the heterogeneity between the included studies, it was not possible to use one assessment tool to assess the quality of these studies.

4.5 Conclusion

This review identified five key factors that contributed to errors when using an ePrescribing system in paediatrics. These include (1) lack of drug dosing alerts, (2) the generation of inappropriate dosing alerts, (3) inappropriate drug duplication alerts, (4) drop down menu selection errors, and (5) system design. Improvements are needed, such as development of dosing support that is based on the drug indication, and use of patient specific order sets and order sentences. Safeguards to prevent patient selection errors, for example, using non-consecutive patient identification numbers for children born from multiple births, or adding in CDS that encourages users to 'second check' their selection may also prevent errors. The system should also prompt users to enter up-to-date information about clinical parameters, *e.g.,* child's weight, which are used in CDS algorithms, and importantly there should be better integration and use of information between the patient's EHR and CDS systems. The concentrations for medications and units used within the system should be standardised where possible. Although medications may be prepared to a range of specific concentrations by pharmaceutical companies, it may be worth considering whether these could be potentially standardised at a system level to prevent calculation errors. Finally, ePrescribing systems should be designed with an understanding of normal work processes and incorporate human factors design principles and usability standards during the development and implementation stages.

Ash *et al.* stressed the importance of educating clinicians about the unintended consequences of ePrescribing systems so as to prevent them from over relying on the technology and making them aware of the potential risk of patient harm.[236] Furthermore, training users on how to use healthcare information systems is important to ensure proper use of the system. The next chapter will therefore explore the training approaches used to

educate prescribers about how to use ePrescribing systems and whether this training included information on how to avoid some of the challenges and pitfalls of these systems.

Chapter 5: The training approaches used to train qualified prescribers to use electronic prescribing systems

It is important that users are appropriately trained to use ePrescribing systems and are aware of how to avoid some of their known pitfalls and challenges. The researcher conducted a review of the literature to (a) describe the approaches used to train qualified prescribers on ePrescribing systems in a hospital setting, and (b) whether training covered the pitfalls and challenges of using these systems. This narrative review has been published: Brown, C. L. Reygate, K. Slee, A. Coleman, J. J. Pontefract, S. K. Bates, D. W. Husband, A. K. Watson, N. Slight, S. P. *A literature review of the training offered to qualified prescribers to use electronic prescribing systems: Why is it so important?* Int J Pharm Pract. 2017 Jun;25(3):195-202. doi: 10.1111/ijpp.12296. Epub 2016 Aug 4.[118] *(Appendix 9)*

5.1 Introduction

As discussed, ePrescribing systems have been associated with a range of potential benefits over paper-based systems, particularly when implemented with CDS.[10, 27, 51, 52] Benefits, including improved patient outcomes, safer patient care and potential cost savings *e.g.,* by prompting clinicians to prescribe generic rather than branded medications,[237] have meant that the number of systems implemented across a diverse range of settings is growing. A key element of the implementation and on-going use of an ePrescribing system is ensuring that users are, and remain, sufficiently trained and competent to use the system effectively. The user training should be comprehensive enough to cover all aspects of how a user may need to interact with a system to undertake their role, but also highlight potential pitfalls and challenges that they may encounter. Ash *et al.* stressed the importance of educating clinicians about the unintended consequences of ePrescribing systems, so that clinicians do not fall into the trap of over reliance on technology and risk patient harm.[236] The number of different professionals (*e.g.,* nurse or pharmacists) who prescribe is also expanding, thus the training provided needs to accommodate users of varying backgrounds and roles. These systems are continuously evolving and offer an ever increasing range of new features, therefore keeping staff informed about system changes and introductory training

is important. Training is not sufficient to overcome poor design, but vendors should be incentivised to develop systems using user-centred design principles.

Organisations face challenges in delivering effective training such as: large numbers of staff, staff resistance/availability to attend training, rotation between wards and specialties, and temporary/short term staff. Little evidence has been published on the training strategies used to familiarise staff with these systems. Online training strategies have been utilised in medical education and can offer a potentially convenient and efficient way of training large numbers of practitioners;[238] however, the effectiveness of this approach for users of ePrescribing systems is not clear.

Some studies suggest that insufficient training is associated with suboptimal use of ePrescribing and EHR systems.[133, 239] Baysari *et al.* found that large numbers of CDS alerts were generated by the improper use of the system, leading to the production of 'technically preventable' alerts.[133] For example, a duplicate drug alert was generated for a new order of 'Paracetamol (500 mg) Tablet: 1g oral Four Times Daily' when there was an existing order for 'Paracetamol (500 mg) Tablet: 1g oral PRN: minimum dosage interval 4h: up to 4 doses per day' already on the system.[133] Shulman *et al.* also found that the rate of errors made by users when using an ePrescribing system decreased over time, demonstrating a learning curve that had taken place.[122] Such studies highlight the pitfalls of these systems and the importance of training and education both in facilitating successful implementation of electronic systems and averting errors. Furthermore, although there are fundamental differences between the provision of healthcare services between clinical settings and countries, there are key elements of the prescribing process that all prescribers must perform, such as the selection of a drug dose and frequency.

The focus of this narrative literature review therefore was to describe the approaches used to train qualified prescribers on ePrescribing systems in a hospital setting. A secondary aim was to investigate whether online training approaches were used and whether information on the pitfalls and challenges of using these systems was covered.

5.2 Methods

5.2.1 Literature Review: Inclusion and Exclusion Criteria

Articles that explored the training of qualified prescribers (including medical and non-medical practitioners) on ePrescribing systems in a hospital setting were included. The researcher chose to focus on the training of qualified and practicing prescribers due to the specific challenges associated with training large groups of busy clinicians, which can be different to the challenges faced with training undergraduate students in a more 'relaxed' environment. The researcher was interested in the types of training approaches used, the relative effectiveness of any specific approach (if discussed), and any challenges encountered. Studies that explored training of undergraduate medical students, training of clinical skills other than prescribing, or the use of ePrescribing or EHRs in medical education (*e.g.,* to enable students to monitor patient progress) were excluded. Studies did not need to include a comparator group, as this may have presented practical and ethical challenges to carrying out the study in a hospital population.

5.2.2 Search Strategy and Study Selection

Three large databases were searched including: Cumulative Index Nursing and Allied Health Literature (CINAHL), Embase (OVID), and Medline (OVID). Sets of search terms employed included "Electronic Prescribing" OR "Computerised Provider Order Entry" in Set 1; "Clinical Decision Support" OR "Decision Support System" in Set 2; "Electronic Medical Record" in Set 3; "Education Clinical" OR "Medical Education" in Set 4; "Education Distance" in Set 5. These sets were combined with the 'AND, OR Boolean operators. The searches were performed on the 15th May 2015. Only papers published in English were considered. Separate searches were conducted for 'all training' and 'online training'. *Appendix 10* shows the search strategy for the 'all training' search in Medline (Ovid).. The timeframe was not restricted. The researcher also searched the websites of vendors of ePrescribing systems supplied in the UK for suggested training approaches. All publication types were included (including editorials and opinion pieces).

5.2.3 Data Extraction and Synthesis

All duplicate articles were removed. Titles and abstracts were initially reviewed followed by the full text by one author (CLT) and any queries were discussed with a further reviewer

(SPS), if necessary. Reference lists were also examined for additional papers. Data were abstracted onto a customised data extraction sheet by one author (CLT), which included variables such as: title of the study; country of origin; and justification for the decision to include *(Appendix 11).* A narrative synthesis of all eligible studies was undertaken. Papers were read and re-read, and key recurring themes and sub-themes were identified iteratively from the data. In keeping with the aim of this review, we focused on the types of training approaches used to train qualified prescribers in the hospital setting and the challenges associated with training.

5.2.4 Vendor Enquiry

The websites of vendors of electronic prescribing systems supplied in the UK were also searched and companies contacted for more details about the training approaches provided. A table of reported findings is provided in the results section: Table 5: *Current training approaches provided by vendors of ePrescribing systems in the UK.*

5.3 Results

The search for 'all training' returned a total of 1,155 publications; after reviewing titles, abstracts and full texts, a total of 1,149 were excluded (Figure 5). After reviewing the reference lists of the remaining publications, one further article was included. A total of seven articles were included, comprising of three full text publications from the US,[240-242] and two from Canada.[241, 243] The remaining two articles were conference abstracts, one from the UK [244] and one from Pakistan/Tanzania.[245] The authors of the conference abstracts were contacted and asked for additional information, including (i) the type of training delivered and whether online training methods were used (if unclear from the publication), (ii) whether an assessment of user's competency post training was carried out and (iii) whether the training was developed internally or by the vendor. Responses were obtained from one of the two authors.[244] Two studies by Borycki *et al.* and Kushniruk *et al.* were included as there was potential for these training methods to be used for practicing prescribers.[241, 243]

The separate search for the use of 'online' training methods returned 25 publications. After reviewing the titles, abstracts and full text, three relevant articles were identified (Figure 6), two of which were previously identified and included in the search of "all training"

approaches. The additional article found in this separate 'online' search was included making eight publications in total.[246, 247]

Identification

Records identified through database searching: (n = 1,155)

Additional records identified through review of reference lists: (n=1)

Screening

Number of titles screened: (n = 1,156)

Duplicate articles and Records excluded (n=1097)

Number of abstracts screened: (n = 59)

Records excluded: (n=44)

Eligibility

Full-text articles assessed for eligibility: (n = 15)

Full-text articles excluded, with reasons: (n =8)

Included

Studies included in qualitative synthesis (n = 7)

Figure 5: Search Strategy Diagram: 'all training'

Identification

Records identified through database searching:

(n = 25)

Additional records identified through other sources

(n = 0)

Screening

Number of titles screened:

(n = 25)

Duplicate articles and records excluded

(n=16)

Number of abstracts screened:

(n = 9)

Records excluded:

(n=4)

Eligibility

Full-text articles assessed for eligibility:

(n =5)

Full-text articles excluded, with reasons:

(n =2)

Included

Studies included in qualitative synthesis:

(n = 3)

Figure 6: Search Strategy Diagram: 'online training'

Typically, a variety of training methods were used such as classroom-based sessions, which included 'run through' demonstrations and practical exercises, as well as face-to-face or ward-based training facilitated by 'super-users' (expert staff members that have received additional training). Super-users were found to play a valuable role in providing ward-level support and reduce the need for costly external training.[248] Tools such as e-learning packages, quick reference guides, a list for keyboard short cuts and 'how to' guides, were also provided.[242, 244]

5.3.1 Traditional Training

Three studies used traditional classroom-based learning to train users; one on a paediatric intensive care unit,[244] another across an integrated delivery system[242], and a third study conducted at two US hospitals.[248] Users were given an overview of the specific features of their system, using a combination of demonstrations, lectures and practical exercises, thus allowing the users to gain 'hands-on' experience of using the system.[242, 244] In particular Bredfeldt *et al.* encouraged staff to customise their own live version of the EHR by creating preference lists, which in turn allowed them to experience the benefits of this functionality immediately.[242] Ensuring clinicians had ample opportunities to attend training sessions was important, so weekend and out-of-hour sessions were organised in one study.[248]

In terms of evaluating user's performance, formal assessments, quizzes and feedback methods were utilised in three studies.[242, 244, 245] Bredfeldt *et al.* evaluated post-training performance of two skills (covered during the training session) to measure the effect of training.[242] Classroom-based training and 'hands-on' activities were found to have been associated with improved utility of certain functions.[242] However, users would have appreciated more opportunities to receive training on the 'live' system and felt that the range of topics covered should be broader.[242] Bredfeldt *et al.* also sent e-mails to users to report their usage of specific features and compared their activity with that of their peers, serving to remind users of the learning material and tracking their progress.[242]

5.3.2 Online training approaches

Web-based demonstrations were used in only one study.[245] Three papers described the work of one team that developed an online portal, which housed a range of simulated versions of different EHRs containing electronic prescribing functionality. Healthcare professional students, practicing professionals and healthcare informaticians were given

access to this portal where they could prescribe for fictitious patients in a safe environment.[241, 243, 247] The portal also provided an opportunity for users to learn about the design of different systems that may be used in clinical practice.[241, 243, 247]

Evaluation of online training methods was limited. Experiences and lessons learned from the University of Victoria's EHR portal appeared to be positive, with users perceiving the experience as valuable and having a greater understanding of how EHR systems were to be used in practice.[241] Ayoub *et al.* did not specify how quizzes were developed or which areas were assessed, although trainees reportedly scored highly in these.[245] Jimenez highlighted the importance of providing timely feedback to users after completing exercises.[240]

5.3.3 Clinical scenarios and exercises

Two studies used targeted clinical scenarios that focused on particular problem areas to train staff. Foster *et al.* developed exercises based on commonly encountered prescribing errors, such as the prescribing of Tazocin® (piperacillin-tazobactam, an antibacterial) at non-standard times.[244] Bredfeldt *et al.* targeted training to specific clinical areas, such as pre-operative patient visits, where there had been a number of support requests from existing users.[242] Developing expertise-specific scenarios relevant to clinicians from different specialist areas was considered important.[240, 247]

5.3.4 Vendor supplied training approaches

Table 5 presents an overview of the training approaches provided by vendors of ePrescribing vendors in the UK.

Table 5: Current training approaches provided vendors of ePrescribing systems in the UK

Supplier	System	Communication Method	Supplier Training
Alert Life Sciences Computing	ALERT Prescription	Emailed 19th April 2015 (no reply) Re-emailed 29th April 2015 (no reply) Information obtained online at http://www.alert-online.com/elearning [accessed 28/04/2015]	ALERT eLearning • Alert e-Learning programme for Alert products can be offered as an alternative or a complement to 'traditional teaching'. • Flexible learning is provided with the ability to access training anytime and anywhere depending on the availability of individual staff. Staff can learn at their own pace and tailor their learning towards key areas of interest. • The e-learning programme uses a variety of multimedia to support learning such as demonstration videos, trainer instructions and animations. It is possible to communicate within the system via chat and forums, which allows end-users to exchange their experiences. • The system also supports tutor-trainee communication through the chat and forum tools. The e-learning programme provides continuous performance evaluation to support end-users as they learn. The content continues to be available after completing individual courses to enable review of learning material. • A specific course ALERT EDIS PHYSICIAN® is available and targeted towards doctors working in the emergency department. This course uses active and demonstrative methods to cover a range of areas including: documenting a chief complaint, ordering medication and exams, access results and discharging a patient. A certificate is awarded to the trainee once 80% of the course has been completed, suggested tasks have been performed and have achieved a pass in the final evaluation. The course takes approximately 4 hours. Further courses are available for example an Introduction to ALERT ® v2.6 which allows end-users to learn more about the functionality of the ALERT prescribing system. • Courses are available for a US and UK populations.

Allscripts	Sunrise clinicals	Emailed 19th April 2015 (no reply) Phonecall 29th April 2015 (no reply) Information obtained online http://uk.allscripts.com/products-services/services/education [accessed 29th April 2015]	• Experiential Learning: Scenario-based simulation learning tool designed for staff members. These self-paced courses allow learners to practice workflows using real-world scenarios in a simulation learning environment. • Training Consulting: Training Consultants provide strategy, guidance and recommendations for any size group who needs end-user "best practice" training guidance. Formal instructor-led classes: • These classes are held in Allscripts training facilities, where attention is given to the learning needs of each individual student. The sessions include extensive training materials, hands on exercises and interactive discussions. • Web-based instructor led classes: These smaller web-based classes are for single topics or customised training needs. Students learn from their onsite organisation, while still receiving the individual attention and hands-on time provided in a classroom setting. • eLearning: Budget-friendly, self-paced form of training is scalable for small offices that need to provide training around a busy office schedule. For very large organisations, the company reported having more staff to train clinicians and office personnel. • Custom Solutions: Any combination of services are available for clients who want to design their own learning path."
Ascribe	Ascribe ePMA	Online material http://www.ascribe.com/solutions-services/Pages/Training-Academy.aspx [accessed 13th May 2015] Phone call 13th May 2015 (spoke with member of	Training academy • Range of training packages • Training can be delivered on-site or within Ascribe office in Bolton or an external venue in London. • Training is typically provided to approximately 6 members of the organisation (a multidisciplinary team is preferred). 'Train the trainer' sessions are delivered to give an overview of the system and features so that they can then carry out end-user training at their organisation. Workshop sessions are also held whereby wider members of the hospital organisation can ask questions and provide comments about features that they would like to see, thereby having some influence into system build. • The 'train the trainers' then deliver end-user sessions, which are designed and

		sales team)	customised according to the specific organisation. For example, lecture sessions, one-to-one training on the ward and, simulation 'dummy stations' whereby staff can access and practice using the system even before it has 'gone live'. Standard training manuals are available from the company however, due to the variations in systems post customisation, organisations typically develop their own training packages. • E-Learning packages have recently been developed to train the trainers; however there is no provision of e-learning material currently for end-users. Although experience suggests trusts often develop their own e-learning training packages or outsource e-learning from external suppliers.
Cerner Corporation	Cerner ePrescribe (Millenium)	Emailed 19th April 2015 (no reply) Material obtained online http://www.cerner.com/uploadedFiles/Content/Solutions/ Education_and_Training/ Learning_Consulting_Services/UK_learning _servicesflyer_2012.pdf [accessed 29th April 2015] Phone call 13th May 2015 (spoke to Lindsey Whittaker 02071074413)	Cerner Learning Services: A range of training options are available which are delivered by learning consultants and educators. Managed Learning Services are available, which offers training across a range of areas to end-users. This service is available as an optional extra and is therefore subject to additional costs. Managed Learning Services include implementation education, technical education, clinical education and leadership and professional skills education. The full range of teams include: 1. Learning consultant/coordinator: Involved in training learning staff and recommending and planning end-user learning. 2. Learning Plan Development Session: A team that works onsite to identify learning needs, resource constraints and best practices in order to develop a tailored learning strategy for the organisation. 3. Learning Task Analysis: A team helps develop end-user learning materials. Critical tasks and assessment questions that validate competency are also identified. 4. Custom Learning Materials Development: Examples include organisation-specific facilitator guide, performance based assessment and supporting materials to assist delivery of instructor led end-user training

			5. Web-Based Training for End Users: Online learning tools, these can be standard or customised. 6. Train the Trainer: Trainer-Advanced training for organisational trainers. 7. Super-User Training: training of designated super-users in specific areas so that they are able to facilitate system use and support staff. 8. End-User Training: Typically a combination of web-based training, instructor led training; activities are performed both in a training setting and as job aids. 9. Advancing Conversion Excellence (ACE) Programme: A team provides support with health care staff during the early stages of implementation. The ACE team assist end-users with limited Cerner experience to gain confidence and expertise. 10. Learning LIVE: An e-learning program to deliver training and support continuous learning. Training is accessible, offering 'just-in-time learning at the point of need' After speaking to Lindsey Whittaker on 13th May 2015, she explained that e-learning is typically not provided to UK organisations unless requested. This is because the UK market tends to want an e-learning package that is exactly customised to the system that the organisation will use and therefore the standard version of e-learning system is seen as less attractive. However e-learning packages can be built and developed with the organisation if needed. Alternative online material such as video clips, which give demos of specific functions, are available and can be accessed at any time.
Civica	Paris EPR and Case Management	Unable to obtain response after multiple emails and phonecalls	
CSC	Lorenzo	Informatio n provided via telephone call 5th May 201 (Sarah Mason, Sales,	Lorenzo and Medchart are systems provided by CSC and therefore have similar training available. Training is delivered through a 'train the trainer' model at the hospital site to selected individuals. Training is classroom based and given to small groups of approximately eight trainees using hands on activities. Training is delivered on specific modules within the system
CSC	Medchart		

		077953900 18)	depending on local needs. Sessions will take place on a standard version of the system. There is a test at the end of the 'train the trainer' sessions to assess competence, after which the in house-trainers will deliver sessions to end-users.
			End-user training is supported by CSC trainers but is delivered by in-house trainers. Training content and delivery varies between organisations, and it is up to the organisation to develop with end-users what training methods will be used.
			e-Learning modules can be provided or developed in collaboration with the trust, however no trust has used e-learning as a sole method of training due to the complexity of the system. Typically classroom based end-user sessions are delivered. A benefit of the e-learning is that it may be accessed off site and at a convenient time for the end-user.
CSE (servelec-healthcare)	PICS	Phone call 13th May 2015 (Lindsay Dransfield, sales, 077151212 44)	There are four strands of learning: 1. Set-up training e.g. setting up a drug formulary and new users on the system. 2. Training around the rules which drive the EPMA and decision support system and ensure these are appropriate for the organisation e.g. Venous Thromboembolism assessments. 3. End-user training; core training about how to use the system e.g. how to prescribe, how to administer. 4. Report training; training on how to manage alerts and utilise information that is gathered on the system. The NHS Trust will identify a multidisciplinary team who will develop training that is delivered to end-users. Servelec will then train these individuals who will then deliver their own training sessions, typically classroom or ward based face-to-face teaching. Standard training materials are available however Trusts are encouraged to develop their own customised versions, which are more specific. Test and training environments exist, which allow clinicians to work safely through the system. Increasingly trusts are requesting to use test patients that are in fact anonymised versions of a real patient to ensure the content and scenario is realistic. E-learning or distance based learning is available or can be developed, however it is used mainly

			for teaching specific features or as a refresher for end-users rather than as an alternative to face-to-face sessions. The PICS system is complex and therefore e-learning would perhaps not be a sufficient sole training method. Video tutorials and demos have also be used which would allow trainees to access learning material from their intranet at a convenient time to learn how to perform specific functions.
Servelec-healthcare	RiO ePMA	Phone call 13th May 2015 (Lindsay Dransfield, sales, 07715121244)	As for PICS system. Both supplied by Servelec.
Epic	EpicCare EMR	Information obtained online: http://www.epic.com/services-training.php [accessed 29th April 2015] Followed up with phone call on 1st May (Company called)	Total recall training: Project team members and key end users from the hospital organisation receive training at a training site in Verona, Wisconsin. Classes are delivered to introduce the system and discuss how it will impact workflows. An end-user learning package is delivered called 'Training Wheels', which aims to prepare end-users in usage of the system. This incorporates e-learning lessons, lesson plans, hands-on experience; post e-learning lessons 'quick start guides' and optimisation materials. Materials are tailored to the specific roles in which they are intended to be used and are scenario based. e-Learning: Scenario based programmes are available. The tutorials guide clinicians through workflows, allowing them to learn at their own pace in a flexible manner. E-Learning may be used as an alternative to or in conjunction with instructor led end-user training.
JAC	JAC EPMA	Information obtained online http://jac.co.uk/files/JAC%20System%20Management%2020140130.pdf [Accessed 5th May 2015]	System Management Training • Refresher training and new training for system managers • Ensure the system is configured to specific needs • Optimisation of the system. Training is typically on-site, and instructor led. (No information provided about specific end-user training or on-line material)

		Email correspondence 5th May 2015 with Craig Rothwell. E-mail address: craig.rothwell@jac.co.uk	
MEDITECH	Version 6.0	Email 22nd May 2015 odiaz@meditech.com Phone call 28th May 2015	Training is provided as part of full system implementation. Meditech trainers from the US are deployed within the trust and will work with the organisation to plan training according to specific needs (i.e. medical training will differ to pharmacist or nursing training content). Meditech will work with the Trust to arrange who exactly will be trained and that decision will be on a case-by-case basis. The format of training is flexible. Options include classroom delivered sessions, which are considered more effective than lectures and one-to-one sessions if needed. The training support is ongoing after the initial implementation. Meditech trainers will visit the Trust after one year to perform 'optimisation usage' to effectively assess how the system is being used and also carry out additional training when new versions are released. An online e-learning module was being developed but was only available for internal use.
Noema Life	Galileo Medication	Email 29th April 2015 aishaq@noemalife.com (Questions provided)	The format of the training was dependent upon the needs of the Trust and users. The vendor could provide class-room based, ward-based, one-to-one and e-learning training. 2. Who receives training delivered from yourselves? Is it only key members of the hospital team who are trained? Or do you provide full hospital training programmes? The vendor can simply provide train the trainer training or deliver hospital/Trust wide training. Dependent on the client's preferences. The vendor recommended that the training should be delivered on-site as it was easier to

| | | | get staff to attend, although it could be done off-site if needed.

The duration of training depended upon the users being trained as well as how IT literate they were and if they have experience of previous EPMA systems. It can range from 2-3 hours to a whole day, particularly for users that require knowledge of different user role functionalities.

If e-learning was provided, this would cover the same topics as would be covered in any other training delivery approach. |
|---|---|---|---|
| QuadraMed Corporation | QCPA | Emailed 19th April 2015,

Reply received 20th April 2015

Information obtained online http://www.quadramed.com/en/solutions_services/clinical_solutions/professional_services/ [accessed 29th April 2015] | Targeted Customised Training:
A range of classes are offered, including- new implementation training, database support training, upgrade service training and customised training.

Training is offered both on and off site.

(No information was provided regarding online training) |
| System C | Medway | Emails (20th April 2015 and 23rd April)

Phone call 29th April (spoke to member of sales team) | A dedicated System C Business Education Specialist is supplied to the Trust, who works in partnership with the Trust training team to provide guidance, training and support.

System C deliver Train the Trainer (TtT) training for the Trust training team, and offer advice on how to deliver end user training. The System C Training Lead will continually assess Trust training staff to ensure that they meet the required competency levels to deliver to end users, and additional training/support can be given to Trust trainers who do not meet the required competency levels. |

| | | | Following completion of TtT the Trust trainers will work on developing the End User Training courses. Once this activity has been completed the Trust Trainers will be asked to deliver their courses to the System C Training Lead to ensure that the system is fully understood. If necessary, the System C Training Lead will provide additional training to supplement any gaps.

Aside from the above, it is a Trust responsibility to organise, plan and deliver end user training, and their decision whether to include consolidation type exercises during this training.

It is the responsibility of each Trust to deliver end-user training. In their experience, Trusts deliver a mixture of training styles dependant on the content and the type of user attending the sessions.

Online learning material is provided for access throughout a project deployment. |
|---|---|---|---|
| TPP | SystmONE | Emailed 19th April 2015 (no reply)

Follow up phone call 29th April 2015 (spoke to member of sales team) | 'Train the trainer' sessions were provided by TPP to designated staff members within the hospital who are given the knowledge and skills to then train end-users within the specific organisation.

TPP will also assist hospital trainers to develop learning materials and tools specific to the organisation's needs. Full end-user training can be provided by TPP, however this is not the preferred method. Top-up sessions are available if required to re-train staff.

Train the trainer sessions are delivered onsite at the hospital and typically last for 5 days, however this will vary by site.

Training on the 'train the trainer' course is typically classroom based. There is no provision for e-learning however the system is integrated with a question and answer style communication functionality to allow queries to be addressed. |

5.4 Discussion

The papers identified a range of approaches used to train qualified prescribers, including the use of 'traditional' training methods, online training, and clinical scenarios and exercises. The

use of a range of different approaches may appeal to different individuals with users appreciative of relevant and tailored clinical-scenarios in particular. The researcher searched for published studies in three large databases. However, it is possible that studies may have been published in other databases or unpublished work (*e.g.,* reports or working papers) may exist in the grey literature. The search only focused on the training of qualified prescribers due to the specific requirements of their training. However, some training approaches used for other groups, such as undergraduate students, may have been potentially applicable and possibly useful. Notwithstanding these limitations, it is clear that there is a lack of published research in this area, thus more evidence is needed. Organisations should also share any lessons learnt from their experiences of training prescribers during the implementation stage and also any follow-up training at a later stage to fill any knowledge gaps.[249]

The papers identified outlined a number of methods used to train qualified prescribers, including classroom-based sessions,[242, 244, 248] demonstrations and 'hands-on' exercises. Some studies incorporated assessment(s), which allowed users to track their own progress and informed senior staff about those who may need further assistance.[242, 244, 245] Clinical scenarios aimed at addressing commonly encountered prescribing errors or frequent technical support requests were also used.[242, 244] Such problem areas may reveal systems flaws that may contribute to the occurrence of errors or poor usability. For instance, although ePrescribing can decrease prescribing of 'non-formulary medicines',[100] formulary alerts were often inappropriately overridden.[237] Therefore, understanding how users interact with these systems is important to inform future training strategies.

This review found that combinations of different learning methods were used, which appealed to the learning styles of different users. For example, Ross and Banchy used a combination of one-to-one and group classroom-training sessions to address the specific needs of medical staff and maximise attendance.[248] This approach was also used when training staff on other non-ePrescribing forms of healthcare-information systems. For instance, McCain *et al.* reported how challenging it was to get nurse and physician users to attend classroom-based training sessions on an EHR system (as opposed to an ePrescribing system) due to their other clinical commitments. Users felt that these sessions failed to address their learning needs by either being too simplistic or too advanced. This resulted in a blended learning strategy being provided that included a combination of computer-based learning exercises and a training CD. This approach facilitated 'self-study' where users could

train at a convenient time and pace,[250] and may be beneficial when training prescribers on ePrescribing systems. Due to the heavy workloads and often unpredictable schedules of prescribers, it would seem reasonable to suggest a training approach that allows users to train at their own pace and convenience. Laramee *et al.* found that participants preferred written guidance on how to perform tasks rather than computer 'help' functions. Organisations should therefore consider providing a range of learning tools to meet users' needs.[250-252] Notably, we only found a relatively small number of studies, which have been conducted either on one particular ward or organisation, thus they may not be generalisable to other settings. The workforce in rural or remote locations for instance, may lack sufficient resources to hire healthcare informatics staff who are important for the deployment and ongoing support of ePrescribing systems. More targeted and accessible approaches such as checklists and toolkits may therefore be useful.[41]

Other training methods employed in practice were not discussed in depth in the small number of articles found in this review. Vendors of UK ePrescribing systems offered a range of training options, such as workshops or e-learning. However, these were typically focused towards key internal staff who disseminated training to others during the implementation phase. Vendors should provide a range of flexible training approaches that can accommodate the requirements and training needs of different organisations.

Many of the vendors contacted described the limited provision of online training, possibly restricted to super-users or for specific training (*e.g.,* about a system upgrade) or explained how such functionality was currently in development. The use of e-learning as a method of training clinicians on an ePrescribing system was considered important in the included studies.[240, 242] A study, which used an e-learning tutorial to deliver educational material primarily to nurses, was associated with high completion rates of the training module (74% of the 2,080 nurses) and perceived improvements in the completeness of documentation within the EHR.[253] The American Health Information Management Association (AHIMA) and the American Medical Informatics Association (AMIA) developed recommendations related to workforce issues during EHR implementation and suggested that a range of innovative learning techniques, including electronic-methods, should be used.[249] E-learning material should be engaging, potentially including interactive scenarios. It should also be simple and concise, clearly specify the learning outcomes, and take care to limit the amount of information presented.[253] With organisations choosing to migrate from one system to another (*e.g.,* Brigham and Women's Hospital in Boston transitioned from a home-

grown system to a commercial system in 2015), and clinicians often rotating between sites (*e.g.,* between a tertiary care and a community hospital) or specialities (*e.g.,* between a medical and a surgical rotation), it is important that users feel able to carry out their key tasks on different systems. Tools such as the University of Victoria's EHR portal that provided users with an opportunity to train on a range of systems may be particularly useful. These 'virtual learning environments' should replicate as much as possible the interoperability issues associated with using multiple systems (*e.g*. failure to integrate allergy information from the EHR into the ePrescribing software)[254] so that prescribers are prepared for these challenges. The importance of intra system interoperability and the need to improve the transfer and use of information between systems is well-recognised in the literature.[45, 255]

Training specifically aimed towards educating prescribers about the challenges and pitfalls of ePrescribing was rarely discussed. However, studies frequently include education and training as a solution to some of "the issues" encountered, or as an explanation for why users fail to use the system as intended.[80, 133, 256, 257] Sittig *et al.* made specific recommendations, such as, providing adequate training opportunities for clinicians to experience the system before implementation; this attempted to enforce a minimum level of training before users were authorised to use the system. They also proposed that organisations deliver 'walk-throughs' of the different processes for specific clinical staff.[257] Foster *et al.* and Bredfeldt *et al. also* highlighted the need to tailor the clinical scenarios and content of training to the role, expertise and tasks performed by the user.[242, 244, 248, 258] Training and assessment approaches should encompass both procedural tasks (*e.g.,* prescribing) and cognitive tasks (*e.g.,* interpreting CDS alerts) so that prescribers realise the full potential of the system.[258] Furthermore, the assessment should measure the user's competency to ensure that they are using the system effectively and appropriately. Importantly, prescribers should be able to identify and address gaps in their own knowledge;[249] learning outcomes can provide a benchmark for users to judge themselves against.[259] Alongside training, it is important for system developers to improve the design and usability of ePrescribing and CDS systems. Increasing CDS alert specificity and sensitivity to produce more 'patient-centred' recommendations is likely to reduce the impact of alert-fatigue and improve patient outcomes.[69, 72] Implementation is costly,[52] therefore the effect of interventions should be evaluated to inform practice.

5.5 Conclusion

Organisations are currently using a range of learning methods to train qualified prescribers how to use electronic systems, including classroom-based sessions, demonstrations and 'hands-on' exercises. Online learning may facilitate the training for many users. Clinical scenarios aimed at addressing commonly encountered prescribing errors or frequent technical support requests were also used. However, the lack of papers retrieved suggests a need for additional studies to inform training and assessment methods. Finally, further research should explore the best way of training users about the pitfalls and challenges associated with electronic systems.

5.6 Summary of Introduction Section

Chapters 1 to 5 have provided background information about the role of ePrescribing and CDS systems in the prevention of medication errors, incorporating the findings from four comprehensive literature reviews. These reviews have outlined the role of CDS, including the recent developments and persisting issues, and has provided an overview of the unintended consequences associated with ePrescribing systems in primary care, secondary care and paediatrics. Additional post-implementation evaluation of ePrescribing and CDS systems is needed to contribute to the understanding about the usability issues encountered with such systems, the workarounds taken to overcome such issues and what features are beneficial for users and why. Finally, a narrative literature review, which explored the training of users on ePrescribing systems, highlighted the range of approaches that were used but also revealed the need for further research in this area so that organisations are better informed of evidence based training strategies.

This PhD programme of work will explore users' experiences of using an ePrescribing system in a UK secondary care hospital Trust, particularly focusing on aspects related to the system's design, customisation and the training users received at this site. The next chapter of this thesis describes the methods used to conduct this research, including an explanation of the rationale for the qualitative approach taken and the specific methods employed in order to address the main aims and objectives of this research.

Chapter 6

Study Design and Methodology

6.1 Introduction

This chapter outlines the study aim and objectives and the research methodology used. This PhD programme of work incorporates two related studies, the second of which arose from the first. The method of both studies will be presented in turn. This chapter will begin by stating the main aim and objectives of the study followed by the rationale for the methodological approach used, and how validity, reliability and generalisability were considered.

6.2 Aim and Objectives

6.2.1 Aim

The aim of this research was to explore users' experiences of using a commercial ePrescribing system in a large UK teaching Hospital.

6.2.2 Objectives

- To explore the key challenges facing users when using specific design features of the ePrescribing system;
- To understand the benefits and challenges of customising and using customised features of a commercial ePrescribing system;
- To ascertain the benefits and challenges of interruptive and passive clinical decision support approaches;
- To explore the training approaches used to educate clinicians on the use of a commercial ePrescribing system.

6.3 Methodological Approach

A qualitative methodology was selected to meet the study's aims and objectives. This allowed a detailed understanding of participants' attitudes and experiences to be gathered and actual usage of ePrescribing systems to be captured. This was in contrast to using a quantitative approach that would have served to test a hypothesis or enumerate the occurrence of events, which was not the purpose of this research.[260]

A decision was made to conduct this study using the framework approach. This method was developed in the 1980s by Ritchie and Spencer for the purpose of applied policy research from a need to address clearly set and predefined objectives, based on specific informational needs.[261] This method was chosen for a number of reasons. Firstly, the specific areas of interest have been identified through literature review and experience of the researcher working as a pharmacist in secondary care. Therefore, approaching the study without such preconceptions, for example, using a grounded theory approach would be unrealistic. [262, 263]   Secondly, a descriptive method of analysis, for example phenomenology, would seek to generate a rich description, or an essence, of users' lived experiences of an ePrescribing and how their life-world contributed to that. However, this method was ultimately rejected for two key reasons. Firstly, the aim of this study was to move beyond description towards developing improvement strategies that could be adopted. Secondly, the researcher sought to focus on the specific system-related and training factors that contributed to users' experiences of using the system. Therefore, an approach that supported an inductive approach to data collection, allowing theories to develop 'bottom-up', whilst acknowledging the need for structure and systematic methods to be used during the analysis was preferred. This provided focus to achieve the study's goals with flexibility to explore unconsidered issues.[264]

Based on the researcher's own stance, that reality may consist of multiple truths, a constructivist/interpretivist approach was taken, that is, reality is constructed through meanings and understandings that have been developed socially and experientially.[265] Meaning may also be formed through interactions with others and historical experiences. Of note, the researcher has experience of working as a pharmacist and interacting with pharmacy colleagues, who have experience of using ePrescribing healthcare information systems, which may contribute additional insight. The researcher's role was therefore to

interpret and make sense of these meanings from the data in context rather than begin with an existing theory.[266]

Two different qualitative methods were chosen to provide parallel insights of different user experiences.[267] These include semi-structured interviews and observations. The following section will detail the chosen qualitative methods and rationale for their inclusion.

6.3.1 Choice of Methods

A range of data collection methods were available and were considered when deciding what methods to use to address the study objectives. Surveys, incorporating both quantitative and qualitative responses, could have been used. However, this would have required qualitative approaches to have been used initially, in order to develop and test the questions.[268] Additionally, there are difficulties associated with collecting in-depth data about users' experiences and probing for explanations to describe any differences identified between groups, when using surveys. Furthermore, this method is often limited by low response rates, particularly among healthcare professionals, which can result in non-response bias.[269] Thus, this approach would not effectively meet the study aim.[270] Focus groups facilitate data to be collected and generated through interaction between a group, allowing discussion, argument and explanation. They also provide insight into a shared experience or could provide a forum to explore proposed improvement strategies.[267, 268] However, there is the risk that certain participants may fail to voice their true opinion or there may be difficulties managing the group dynamic, for example, if some participants are particularly vocal, while others are reluctant to participate, or due to a hierarchy between more senior and junior staff.[267] Furthermore, the practical difficulties of recruiting busy clinicians, which would require them to leave their ward at the same time to attend the focus group, meant that this approach was deemed unsuitable.

6.3.1.1 Semi-Structured Interviews

Semi-structured interviews were selected over either unstructured or structured interviews. This method is usually based on a flexible topic guide that provides structure to the conversation, while the use of open questions also allows respondents to provide their views fully and focus on the aspect affecting them.[268] The adaptable nature of semi-structured interviews allows topics to be explored in detail, and not constrained by space in a questionnaire or survey.[267] The ability to modify questions according to participant

responses was felt to be important, particularly as a range of professionals were to be included and their experiences of a single process were likely to be varied. A structured interview however, would provide fewer opportunities for the interviewer to build rapport with the interviewee and may limit the responses obtained. Carrying out unstructured interviews would lack the focus needed to address the specific research questions. Additionally, they tend to be longer in nature and therefore would not be practically feasible due to the time constraints of busy hospital staff.[271]

6.3.1.2 Field-usability Observations

According to Pope *et al.* observing the behaviour and interactions of a team in their workplace allows researchers to *'uncover everyday behaviour rather than only rely on interview accounts'*.[268] In order to gain an understanding of the human-computer interaction, participants were observed using the ePrescribing system as part of their daily routine in their usual work environment. Events, such as ward rounds or medication administration rounds, were targeted as they were likely to feature high usage of the ePrescribing system. The researcher entered the field as a known researcher in order to conduct direct observations. Using this method, data could be collected that would not have been captured or previously considered through questioning methods alone. Furthermore, this approach enabled the researcher to observe what participants do, rather than rely on narrative reports from interviews, which may be affected by issues such as recall bias. An observation template *(Appendix 12)* was used in order to guide the collection of focused data. The free-text field in the template also ensured that additional, perhaps unexpected data, could be documented to enable new theories to emerge.[272]

6.4 Validity and Reliability

A range of strategies were used to limit bias and increase the reliability of the research findings.

6.4.1 Theoretical Sampling

A theoretical sampling approach was employed, defined by Glaser as '*the process of data collection for generating theory whereby the analyst jointly collects, codes, and analysed their data and decides what data to collect next and where to find them, in order to develop their theory as it emerges'.[273]* The initial decision for the sample was based on the typical core

users of the ePrescribing system, who used the system as part of their professional role *i.e.,* doctors, nurses, pharmacists and pharmacy staff. Subsequent analysis revealed concepts and developed understanding of the data and, due to the iterative process of this study, additional members of the hospital informatics team were included. Furthermore, on identifying the views and experiences of users of the ePrescribing system, additional insight was sought from key stakeholders from four different hospital Trusts who were involved with the training of staff in their respective Trusts.

6.4.2 Data Triangulation

A range of users (doctors, nurses, pharmacists, pharmacy technicians) were interviewed and observed across four adult wards of differing specialities (renal, cardiology, general medical and general surgical), to obtain a variety of perspectives and enrich understanding.[267, 274] Additionally, a combination of data collection methods, including semi-structured interviews and observations, along with the researcher's field notes were used to test and validate any emerging findings.[130]

6.4.3 Examination of disconfirming instances

Disconfirming instances, *i.e.,* sections of the data, which do not support the general trends emerging from the data were actively sought.[275] This was important to refine the analysis and data collection so that the majority of cases could be explained and additional themes explored or indeed rejected. [274, 276] This was the case when examining one junior doctor's account about the use of drug interaction checks for patients prescribed cardiac medicines (see section 9.1.3 for further details). Although this doctor spoke about how he did not see a role for interaction alerts because these medications were often prescribed together, on closer examination the researcher felt that this example could actually be used as a reason to support the use of CDS and overcome naivety or a lack of knowledge about drug interactions. The junior doctor did not appear to fully appreciate how cardiac medicines, when prescribed alongside other medications could result in a range of serious interactions.

6.4.4 Peer debriefing

Peer debriefing is *'the review of the data and research process by someone who is familiar with the research or the phenomenon being explored'.[178]* During the data collection and analysis, emerging themes were discussed with the researcher's study supervisors and during peer debriefing sessions. The aim of this was to uncover any biases or previously

unconsidered concepts and test the analysis. Credibility was also sought by discussing the study with fellow researchers and presenting the results at conferences, so that the findings could be challenged by individuals who were external to the study.

6.4.5 Clear account of methods

A clear account of the process for data collection and analysis has been provided in this chapter and all published papers, such that the reader is clear about the methods used and any factors that may have contributed to the findings and interpretations made. A comprehensive overview of the five stages of analysis used in the framework approach are provided in section 6.8; use of this approach allows the reader to understand how theories and explanations were developed from the data throughout the process.[274]

6.4.6 Reflexivity

Throughout data collection and analysis, a research journal was kept to record notes of any personal reactions or views that may help explain the development of theory, in addition to practical information, such as the date and time of data collection.[274] Here, the researcher also noted any biases or preconceptions that she may have held to enhance the credibility of the findings so that these could be considered as the data were analysed.

6.4.7 Relevance

The study site and context in which the data were collected has been described in detail. While these results should not be inferred as generalisable, an attempt has been made by using theoretical sampling techniques to present the experiences from a range of participants across different wards. This has provided some transferable concepts, which the researcher hopes will be of relevance to different organisations where they can be further explored and tested.[274]

6.5 Overview of the programme of work

This programme of work consisted of two parts: the main study, which involved conducting semi-structured interviews and observing users of a commercial ePrescribing system across four adult wards in a large hospital NHS foundation Trust. The aim of this research was to explore users' experiences of using a commercial ePrescribing system in a large UK teaching Hospital.

The findings from the main study prompted further enquiry into the issue of how users were trained to use ePrescribing systems and thus led to a second follow-on -study. This study sought to determine what training approaches were being used by different UK hospital Trusts in order to educate their hospital staff on how to use these systems and gain a deeper understanding of what the relative benefits and challenges of these approaches were. Relevant data on training from the main study was incorporated into the analysis for the second study.

6.6 The Main Study

6.6.1 Aim

The aim of this research was to explore users' experiences of using a commercial ePrescribing system in a large UK teaching Hospital.

6.6.2 Objectives

- To explore the key challenges facing users when using specific design features of the ePrescribing system;
- To understand the benefits and challenges of customising and using customised features on a commercial ePrescribing system;
- To ascertain the benefits and challenges of interruptive and passive clinical decision support approaches;
- To explore the training approaches used to educate clinicians on the use of a commercial ePrescribing system.

6.6.3 The Study Site

6.6.3.1 Hospital selection and description of the system

The study took place at a large tertiary care teaching hospital in the North of England. The Trust is a large teaching hospital offering a range of specialities, more than any other group of hospitals outside of London. It has over 1,800 beds and manages over 1.3 million patient contacts every year. Between October 2008 and March 2011, NuTH implemented a commercial ePrescribing system across all general wards, excluding paediatrics. Implementation in paediatrics was postponed until May 2016, due to development of

software for this specialised patient population. The majority of medications were prescribed using the system with the following exceptions at the time of starting data collection: chemotherapy orders (which were entered into a separate order entry system), patient controlled analgesia, epidurals, IV fluids and high frequency eye medication (which were ordered on paper charts). Orders were typically selected from suggested structured order sentences, which included the medication name and a range of doses and frequencies via a drop-down menu. Orders were screened for problems such as drug allergies, and the system presented these problems to the user immediately in the form of an alert, when appropriate. Orders could also be entered using free-text information; however, the system was not able to perform any clinical checks on these orders. In terms of clinical decision support, allergy checking was live on the study wards, drug interaction checks were inactive with the exception of a few tailored alerts that had been created in response to specific issues, and order sets had also been developed for certain treatments. Pharmacists clinically screened and validated medication orders electronically in the system and nurses also documented administration into the ePrescribing system. The ePrescribing system included a 'pharmacy task list', which was automatically populated if a patient was either prescribed a (i) high-risk drug, (ii) had been newly admitted and needed a medication review or (iii) had a discharge prescription that needed to be clinically validated.

The ePrescribing system had been implemented on the adult study wards for over six years prior to the study. Therefore, any issues encountered during data collection were unlikely to be due to 'teething problems' experienced when a new system is first implemented. However, the system was being continuously developed throughout the data collection period, with certain features newly added or modified (*e.g.,* renal dosing support). Users this often mentioned this in their interviews.

6.6.3.2 Ward Selection

Data collection occurred on a general medical ward, with a focus on gastroenterology, a general surgical ward, with a focus on orthopaedics, a specialist cardiology ward and a renal ward in order to capture user experiences across a range of different specialities.

6.6.4 Ethical Approval

This study received favourable NHS ethics approval in 2013, (IRAS Project ID: 141106 Ref: 14/NE/0072) (Appendix 13). The study was also approved by Durham University ethics committee (Appendix 14).

6.6.5 Inclusion Criteria

Ward staff who used the ePrescribing system as part of their day-to-day work on one of the four study wards were eligible for inclusion. This included:

- Doctors and non-medical prescribers, who used the ePrescribing system to enter drug orders;
- Pharmacists and Pharmacy staff who used the system to clinically validate prescriptions and identify patients for review;
- Nurses who use the system to administer medication and record information;
- Hospital informatics team members who were responsible for developing the system across the study wards and throughout the hospital.

6.6.6 Recruitment of participants

The researcher was accompanied to the ward by the ward pharmacist on their first visit who made initial introductions to members of the ward team. Subsequently, a recruitment pack, containing an invitation letter *(Appendix 15)* and information leaflet *(Appendix 16)* were given to members of the ward staff in each of the wards by the researcher and/or ward pharmacist to find out if they would like to participate in a semi-structured interview or be observed using the system as part of their usual workflow. Each member of ward staff was given the opportunity to ask questions about the study and, if they agreed to participate, they were also asked to complete a consent form *(Appendix 17).* Participants were advised that entry into the study was entirely voluntary and that they could withdraw at any time. When participants suggested further members of ward staff who they felt would be beneficial to interview, the researcher approached that member of staff on the ward with the recruitment pack and invited them to take part in the study.

Interviews were carried out until thematic saturation was reached, that is, until the themes suggested by interviewees began to repeat themselves and subsequent participant interviews yielded no new themes.[277]

6.6.7 Main Study Interview Schedule

Participants were questioned using open, non-leading questions from an interview schedule *(Appendix 18).* In particular the questions explored:

- Users' experiences of using the system and their likes and dislikes;
- Whether the system had been tailored to their specific needs and whether these changes were useful;
- The difficulties encountered when using the system;
- The workarounds employed by users to overcome those difficulties;
- User opinions on what improvements could be made to the system.

Prompts were used to probe for a deeper understanding and to clarify and explore participant responses further. In addition, probing allowed the researcher to obtain further relevant information and challenge inconsistencies in a non-confrontational manner.[276] Short and clear questions were used to maximise understanding and clarification was given, if required. As a range of professionals were interviewed, questions were tailored to the participant experiences and knowledge, with role-specific prompts used to generate thought and consideration of a particular area.[276]

6.6.8 The Main Study Semi-Structured Interviews

Participants were interviewed at a mutually convenient time and location within the hospital premises. The interviews took place in an office or empty room away from the ward, which was quiet and allowed for candid conversations to take place. The interviews lasted between 17- 70 minutes. All interviews were audio-recorded with permission and transcribed verbatim together with accompanying field notes. Notes were also made by the researcher to capture any non-verbal data.

6.6.9 The Main Study Observations and Location

The researcher recorded the range of processes carried out by users of the system, the difficulties participants encountered and how such issues were overcome. Detailed notes were also taken to include the comments and actions of participants and where possible any comments or statements were noted verbatim to provide rich supporting data; these were indexed as 'OC' (observed comment). The researcher also noted her own personal views and theories, which allowed any theories that had emerged to be critiqued. These were indexed

'SC' (subjective comment) to facilitate recording.[276] The researcher made all efforts not to be obtrusive and interrupt the participant in order to limit the Hawthorne effect.[276] On occasions where participants tried to 'talk through' their actions the researcher reminded the user that this was not necessary and that the purpose was to observe the system being used as it normally would be. In total, 35 hours of observations were conducted. The observation field notes and any related reflections were transcribed verbatim.

6.7 The Follow-on Study

6.7.1 Aim

To describe the training strategies used to train ward staff how to use ePrescribing systems across four different NHS hospitals in England.

6.7.2 Objectives

- To outline the different training approaches used to train ward staff on how to use ePrescribing systems;
- To gain an understanding of the benefits and challenges associated with using specific training approaches.

6.7.3 The Research Sites

A relevant member of staff, with suitable expertise of training prescribers on the ePrescribing system at their hospital Trust, was contacted at four different NHS hospitals in England. These NHS Trusts were purposefully selected for two main reasons: 1) they had a well-established ePrescribing system in place, and 2) the Trusts represented a range of different and commercially available ePrescribing systems. These included:

1. A large academic teaching hospital Trust in the North of England (system A).
2. A large academic teaching hospital trust in the East of England (System B).
3. A major teaching hospital Trust in the South of England (System C).
4. A large acute hospital trust in the North of England, which was in the process of migrating from one ePrescribing system (system D) to another (system A).

6.7.4 Ethical Approval

Full NHS ethical approval was not required to conduct this study as it was classed as service evaluation. Ethical approval was obtained from Durham University in July 2015 (*Appendix 19)* and all local approvals were sought and received from each individual Trust before the study commenced.

6.7.5 Inclusion Criteria

A hospital staff member with the relevant experience and/or knowledge of training prescribers on the ePrescribing system was eligible to take part in the study. All staff willing to participate must have been able to give informed consent. Any staff member without the relevant knowledge and/or experience of training prescribers was excluded.

6.7.6 Recruitment of Participants

An email was sent to a senior member of the hospital pharmacy team of each hospital, explaining the purpose of the study. The senior member of the pharmacy team was then asked if they would like to participate or identify an appropriate member of their staff with the relevant knowledge and experience to speak to. Individuals with the relevant knowledge and experience of training staff at each site were given the opportunity to participate. They were provided with a participant information leaflet and given the opportunity to ask questions. If they agreed to participate in a semi-structured telephone interview, they were also asked to provide verbal consent. It was explained that entry into the study was entirely voluntary and that they could withdraw at any time.

6.7.7 Interview Schedule

Participants were questioned using an interview schedule, with open-ended questions *(Appendix 20).* The questions explored:

- The types of training and support offered to staff;
- Whether the training strategy and content was developed by the companies that install the systems or was internally created;
- How the training was facilitated, for instance, who usually conducted the training;
- What parts of the training went well or not so well;
- Whether there were any specific 'lessons learnt' from their experiences.

6.7.8 Semi-Structured Telephone Interviews

Participants were interviewed over the phone at a mutually convenient time. All interviews were audio-recorded with permission and transcribed verbatim, together with accompanying field notes. The interviews lasted between 37-42 minutes.

6.8 Data Analysis

6.8.1 Framework Approach

The researcher employed the framework approach for this study. The approach supports inductive qualitative inquiry, while using a clear and systematic approach for analysis. The transparency of the analysis process offered by using the framework approach was of particular importance to the researcher.

There are five steps involved in the framework approach, each of which is described in detail below.[264, 276, 278, 279]

6.8.1.1 Familiarisation: The data were initially reviewed and sorted to make it more manageable. The researcher immersed herself in the data by listening to the interview audio recordings, reading and re-reading the transcripts and studying the observation notes. From this, the researcher began to identify emerging and recurrent themes and key ideas in context, relating to the initial research questions surrounding the users' experiences of using the system, what difficulties they encountered and any workarounds they took to evade such difficulties. Familiarisation was carried out until the range of circumstances and characteristics within the data had been recognised.

6.8.1.2 Identifying a thematic framework: The researcher returned to the notes made during the familiarisation stage and identified key issues. The recurrent concepts and themes were used to construct a thematic framework that data were assigned to. This involved consideration of the issues identified in the original aims and objectives as well as any new issues that were generated through data collection. The framework developed as it was applied to transcripts and became more responsive to emerging themes, due to interpretation of meaning and making connections between ideas throughout the process.

Thematic Framework

1. Challenges facing uses with specific system design features

    1.1. Challenges with the 'Medication List'
    1.2. Challenges viewing test results
    1.3. Challenges viewing or documenting information
    1.4. Challenges using disparate systems

2. Error Prone Orders

    2.1. Unstructured orders
    2.2. Non-synchronous dosing regimens
    2.3. Non-standard dosing times
    2.4. Flexible or variable prescriptions

3. Workarounds

    3.1. Mandatory functions
    3.2. Repetition of tasks
    3.3. Improved visibility
    3.4. Clarification of prescriptions
    3.5. Paper orders
    3.6. Paper pharmacy task list

4. Customisation

    4.1. Customisation of the screen layout
    4.2. Creation and use of order sentences, order sets and favourite lists
    4.3. Insulin ePrescribing
    4.4. Creation and use of the pharmacy task list
    4.5. Approaches to clinical decision support

5. Training Approaches

    5.1. The approaches used
    5.2. Knowledge gaps
    5.3. Benefits and challenges of formal approaches
    5.4. Benefits and challenges of informal approaches

Figure 7: The Thematic Framework

6.8.1.3 Indexing: The thematic framework (a workable list of themes and sub-themes) was applied systematically to all textual data, by annotating each transcript with codes using NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 10, 2012. This involved reading the data in fine detail and making a decision about whether single or multiple themes existed that revealed patterns and interconnections, which was important for subsequent analysis. By clearly annotating transcripts, this method offered transparency and enabled the reader to see how themes were emerging. The initial thematic framework was discussed with the researcher's study supervisors and continually refined during indexing to include previously unconsidered themes, divide themes based on differences that emerged from the data and combine themes when those initially chosen were found to be overly refined and caused the data to be fragmented.[276]

6.8.1.4 Charting: A spreadsheet was used to create a matrix. The data were sorted by grouping similar content together, according to the appropriate part of the framework and charted into a matrix. The charts had headings and subheadings, which were generated from the thematic framework or research questions. A thematic approach to charting was adopted. Each key theme was described on a separate chart, each sub-theme was assigned a column and each respondent or observation period had a row on the chart, *e.g.,* a chart for customisation, which included headings and subheadings along the 'χ' axis and each respondent along the 'γ' axis, with the professions grouped together (Table 6). A total of five charts were produced for each of the key themes. Key points were summarised by the researcher and charted. At this stage it was important to reduce the data into manageable amounts, whilst retaining the 'feel' and 'participant's presence' in the data, for example by retaining the participant's own language. The last column was kept free; to document the researcher's own comments, thoughts and observations so that it could be distinguished from the participants. By referencing the original text, which corresponded to the thematic chart, it was possible to return to the data for subsequent review and refinement of the analysis.

Table 6: Example of Charting

Thematic Chart Challenges facing users using specific design features					
Sub-theme number	1.1	1.2	1.3	1.4	Researcher Comments
Sub-themes	Challenges with the Medication List	Challenges viewing test results	Challenges viewing or documenting information	Challenges using disparate systems	
P5; Nurse	This nurse felt that it was quite easy to miss doses when she was administering medications, as lots of scrolling was required up and down and along the screen. Doses scheduled for non-standard times could be overlooked as they would be further along the screen. It would be better if the system just displayed the doses that were due at that time.		The nurse found it difficult to see on the system whether a medication had been requested from pharmacy. So, she would sometimes err on the side of caution and send a second request or possibly sometimes didn't make a request at all.	Depending on the ward different areas use different processes- *e.g.* some may prescribe IV infusions on the ePrescribing system whereas others just use a paper record. This can be confusing as the nurse may not be sure which one to 'sign off'.	• Non-standard times easily missed. • Duplicate requests. • Duplicate records contributing to confusion.
P16; Doctor	The doctor thought that the medication list could be quite complex, particularly as suspended/ finished courses appeared on there even when they were no longer being given.	It was difficult to see a trend in some results over time if they were separated with lots of other results in the middle. For example, for tests that were taken more frequently *e.g.,* such as BMs or INR results.	MRSA status of a patient is indicated within a screen that can only be accessed by noticing a 'yellow star' and then clicking onto a separate tab 'problems and diagnoses', which would take the user to another screen. It would be useful if the user could hover over their name and find out important information about MRSA status etc. without having to take these additional steps.	Patient's observations are recorded on paper. The user had experienced instances where the paper chart had been lost. This was an issue as they needed that information to make a clinical prescribing decision.	• Medication list can be confusing. • Difficult to see trends in test results. • User needs to know what symbols mean. • Lots of steps involved in accessing information. • Loss of paper records.
P23; Pharmacist	The pharmacist found it inconvenient having three places (med list, summary and chart) to check for medication information, which required lots of scrolling to figure out what was active, discontinued etc.	The pharmacist recalled how it was not easy to review a patient's blood test results compared with other systems they had used. Although they could generate a graph it didn't include the dates of results - this user preferred to have the results and the dates. They also described how they were scrolling so much it was easy to miss-read a line	When the user was reading the drug information for certain medications it sometimes 'cut off' pieces of information about the order so the pharmacist had to hover over it to find out more- user thinks that it should be clearly visible on the screen and that they should not have to make additional effort to see it.	There were lots of ordering approaches for nurses to 'med request' (paper and electronic) so that often nurses did not know what to do for the best. When urgent there was a tendency to take a paper note down to pharmacy however, there were issues with being out of touch with paper orders and whether the order forms were available. Also, it was not always clear whose responsibility it was to order medications so they may be missed. ambiguity	• Scrolling increases risk of missing information. • Graphs missing dates of results received. • The system curtailed some important information. • Duplicate ordering methods can cause confusion.
Observations 16.1	Not all users routinely checked the drug summary when reviewing patients. Therefore, they did not actually know if the patient had been receiving a dose or not. Pharmacist admitted that she sometimes forgot to check that screen and as it's very busy/ lots of information it was hard to have a quick glance.		A free-text prescribing note had been ignored for several weeks for a patient taking hydrocortisone. Free-text comment was less noticeable on the screen compared to the coloured boxes that display the prescribed dose.		• Computer screen display very busy. • Free-text comments often ignored.

The data were organised according to the main themes and sub-themes in the charts. The researcher used these charts to define concepts and map the nature of the phenomena to make associations between categories (Figure 8). The researcher compared and contrasted the data between participants and clinical areas. The aim at this stage was to move beyond description and instead provide explanations and develop strategies from the recurring patterns and associations within the data. The researcher attempted to develop an understanding of what was happening within a theme and identified links between individual characteristics and the phenomena.[276] The charts facilitated this process and revealed similarities in the experiences of different professionals when viewing medication-related information; for example, both nurses and doctors recalled how they found it difficult to check what dose of warfarin a patient had been prescribed and described how they had to be extra careful interpreting that information on the system. Differences were also identified between individuals of the same profession, but with different amounts of clinical experience. For example, more junior doctors appeared to have a better grasp of the system's functionality compared to their seniors (section 10.1.2). As more data were examined sub-themes were grouped together or further refined.

The researcher then began to develop explanations for the emerging patterns within the data. The linkages between phenomena were presented using maps, to improve understanding and clarity. Any linkages in the data were then examined closely and challenged in order to understand the associations and contributing factors. For example, using the scenario above, which found that junior doctors appeared to have a better grasp of the system functionality compared to their seniors, closer examination revealed that there was a difference in training approaches for these two groups, including between foundation year 1 and 2 trainees and speciality training doctors, when they started working for the Trust, which may partly explain this. The researcher also examined 'disconfirming instances' in the data to further refine the explanations presented and ensure that themes had been fully explored or indeed in some cases rejected. For example, investigation of one newly qualified junior doctor' statement that drug interaction checks were not necessary on the cardiology ward because most of the drugs work 'well together', was actually re-coded as a possible reason to support the use of drug interaction CDS within the system. Many medications that are prescribed for cardiac conditions, interact with other cardiac medicines and/or any pre-existing medications some of which could result in serious harm. The researcher felt that the naivety demonstrated by this doctor, who assumed that interactions were unlikely in his

patients, was in fact a reason why such checks were important in a system, as he demonstrated that he 'did not know what he did not know' and CDS could potentially highlight this knowledge gap (section 9.1.3). Other studies in the literature were also reviewed to suggest additional linkages that may exist across the data. A diary was maintained, in which ideas and initial interpretations were noted and further discussed with study supervisors.
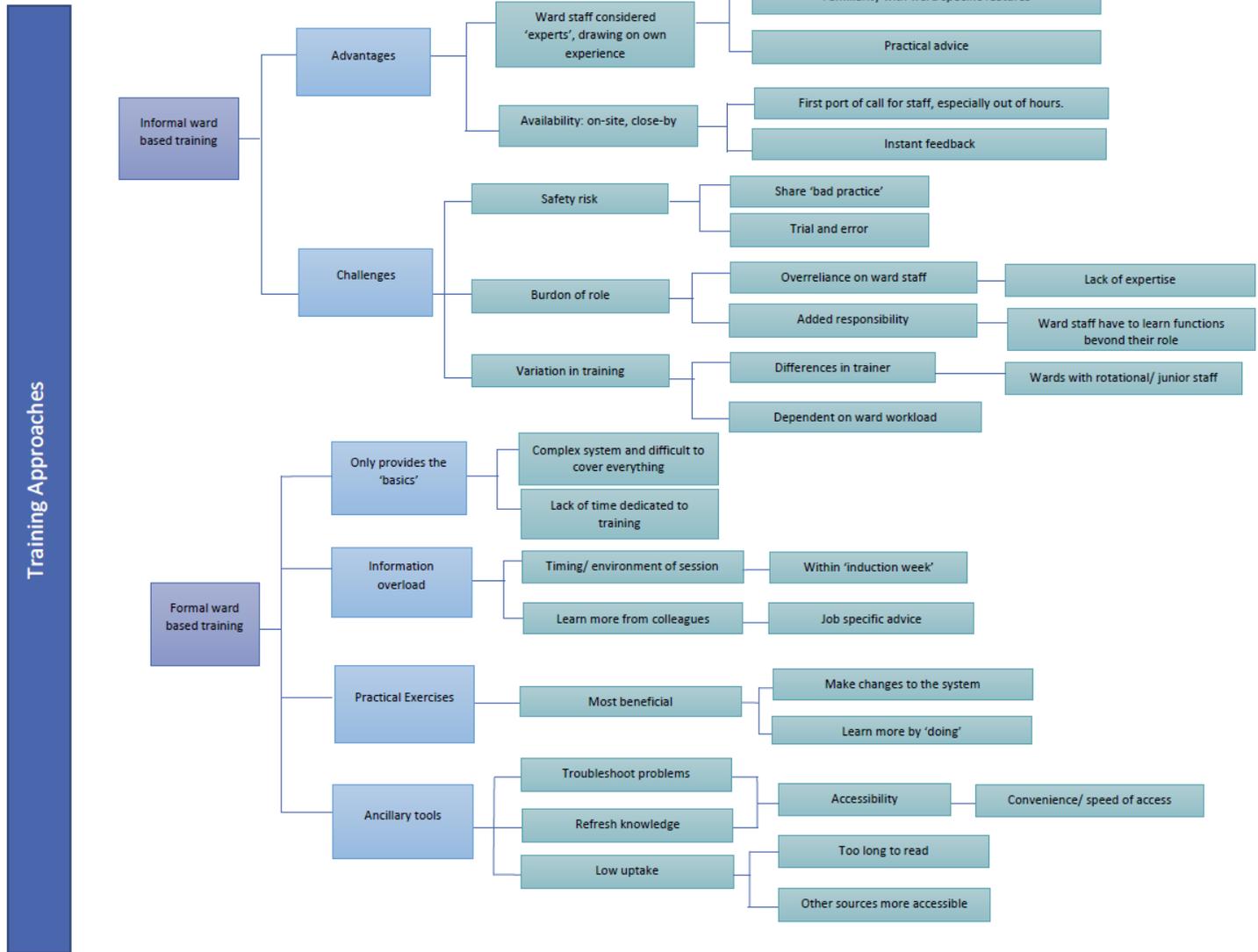
Figure 8: Example of mapping for the different training approaches theme

6.9 Referencing quotes within the text

Quotes and extracts taken from the researcher's observation notes and semi-structured have been included in the results section. These have been entered using italics and in quotation marks. The participant ID code comprises of a unique ID number, followed by their profession only, in order to protect their anonymity *(e.g., P3; Nurse).* Observation extracts have also been given a unique ID, where the ward letter indicates a particular ward speciality, which is not the ward number, followed by the observation session (*e.g., Observation; Ward A.4*, refers to observations taken place on one ward, during the researchers fourth visit to that ward).

The use of brackets '(…)' within a quotation, means that the researcher removed a piece of text from the sentence, for instance to improve readability.

Square brackets '[…]', have also been used within quotations, where the researcher felt that it would be useful to add additional text or clarification for the reader *e.g.,* to explain the meaning of an acronym.

6.10 Participants

6.10.1 Main Study

The researcher conducted a total of 32 interviews lasting between 17-70 minutes and 35 hours of ward-based observations. A breakdown of the participants and observations have been included below (Table 7 and table 8) (to maintain anonymity the wards have been identified using a code *e.g.,* A, B, C or D):

Table 7: The role and ward code of participant

Participant ID Code	Profession	Ward
P1	Staff Nurse	Ward D
P2	Ward Sister	Ward C
P3	Staff Nurse	Ward C
P4	Charge Nurse	Ward A
P5	Staff Nurse	Ward D
P6	Pharmacist	Ward A
P7	Doctor (Speciality Trainee)	Ward D
P8	Doctor (Speciality Trainee)	Ward D
P9	Senior Nurse	Ward A
P10	Ward Nurse	Ward A
P11	Doctor (Speciality Trainee)	Ward B
P12	Doctor (Speciality Trainee)	Ward B
P13	Doctor (Speciality Trainee)	Ward B
P14	Staff Nurse	Ward B
P15	Doctor (Foundation Level)	Ward B
P16	Doctor (Foundation Level)	Ward B
P17	Doctor (Speciality Trainee)	Ward C
P18	Doctor (Foundation Level)	Ward C
P19	Pharmacist	Ward C
P20	Doctor (Foundation Level)	Ward A
P21	Pharmacist	Ward B
P22	Doctor (Consultant Level)	Ward C
P23	Pharmacist	Ward A
P24	Doctor (Speciality Trainee)	Ward A
P25	Doctor (Speciality Trainee)	Ward A
P26	Doctor (Speciality Trainee)	Ward D
P27	Pharmacist	Ward B
P28	Doctor (Consultant Level)	Ward D
P29	Doctor (Registrar Level)	Ward D
P30	Pharmacist	Ward D
P31	Pharmacist	Ward C
P32	Pharmacist	Informatics

Table 8: The observation ID, date, ward code and duration of observation periods

Observation ID	Date	Ward	Duration
Observations; Ward A.1	1st April 2016	Ward A	2 hours (9.35am – 11.39am)
Observations; Ward A.2	27th July 2016	Ward A	1 hour 15 minutes (12 noon-13.15pm)
Observations; Ward A.3	2nd August 2016	Ward A	4 hours (09.15 am – 13.15pm)
Observations; Ward A.4	9th August 2016	Ward A	1 hour 40 minutes (11.20 am – 12.59pm)
Observations; Ward A.5	9th August 2016	Ward A	2 hours 48 minutes (17.38 pm-20.26 pm)
Observations; Ward B.1	9th March 2016	Ward B	1 hour 15 minutes (11 am- 12.15pm)
Observations; Ward B.2	28th July 2016	Ward B	5 hours 15 minutes (08.00 am-13:15pm)
Observations; Ward C.1	18th April 2016	Ward C	1 hour 23 minutes (10.45 am – 12.08pm)
Observations; Ward C.2	19th April 2016	Ward C	1 hour 12 minutes (09.08 am – 10.20 am)
Observations; Ward C.3	19th April 2016	Ward C	1 hour (11.45 am-12.45 pm)
Observations; Ward C.4	19th July 2016	Ward C	35 minutes (09.15 am – 09.50 am)
Observations; Ward C.5	21st July 2016	Ward C	1 hour 5 minutes (08.55 am – 10.00 am)
Observations; Ward D.1	25th February 2016	Ward D	1 hour 20 minutes (10.30 am – 11.50 am)
Observations; Ward D.2	2nd March 2016	Ward D	1 hour 52 minutes (9.30 am -11:22 am)
Observations; Ward D.3	3rd March 2016	Ward D	1 hour (12.30pm- 13.30pm)
Observations; Ward D.4	14th June 2016	Ward D	1 hour 25 minutes (11.00 am – 13.25 pm)
Observations; Ward D.5	20th June 2016	Ward D	2 hours 30 minutes (9.45 am – 12.15 pm)

6.10.2 Follow-on Study

The researcher conducted semi-structured interviews with participants who were involved with user training on four different ePrescribing systems across four different NHS Foundation Trusts. A breakdown of the participants is provided in table 9.

Table 9: Second Study Interview Participants

Participant ID Code	Profession	Site
P33	Informatics Pharmacy Technician	Site A
P34	Chief Clinical Information Officer	Site B
P35	Informatics Pharmacist	Site C
P36	Informatics Pharmacist	Site D

6.11 Chapter Summary

This chapter provides an overview of the qualitative study's aims and objectives, the methodological approach taken, and how validity and reliability were considered by the researcher. The programme of work was then discussed, which outlined details of the study site, recruitment and how data collection was performed for both the main study and smaller follow-on study. Finally, the researcher has described in detail the chosen analysis method and procedure taken to generate findings.

The following four chapters describe the findings obtained from these interviews and observations, including the key themes and sub-themes.

Chapter 7

What are the key challenges facing users when using specific design features of the system?

This chapter will explore the various challenges facing users when using specific design features of a commercially procured ePrescribing system as part of the main study. This includes design features related to (a) the patient's electronic medication lists, (b) viewing and documentation of medical and laboratory information, for example viewing test results in a graphical format, (c) documenting allergy information and (d) viewing free-text comments and 'special instructions'. Furthermore, the researcher reflects on the challenges related to the use and meaning of symbols and the problems experienced when disparate systems are used to create a discharge prescription for a patient. The researcher also describes the workarounds used by health care staff to overcome some of these challenges and how these workarounds, in themselves, could be error-prone.

7.1   Challenges with the patient's electronic medication lists

7.1.1   Medications displayed in the list

The patient's electronic medication list presented a simplified list of the medication that has been prescribed for the patient, including the start date (*e.g.,* 15/Jul/2016), order name (*e.g.,* codeine), status (*e.g.,* ordered or discontinued) and details such as dosage, frequency, and route of administration (See Figure 9). However, it did not display any information related to whether the medication had been administered (or not). At the top left-hand corner of the screen, the user had the option of selecting from a drop down menu 'all medications (all statuses)', 'all active medications', or 'all discontinued medications'. The 'all medication (all statuses)' view provided a list of medications, which included those that were currently active as well as those discontinued, while the 'all active medications' tab and 'all discontinued medications' separated these medications out into their respective lists.
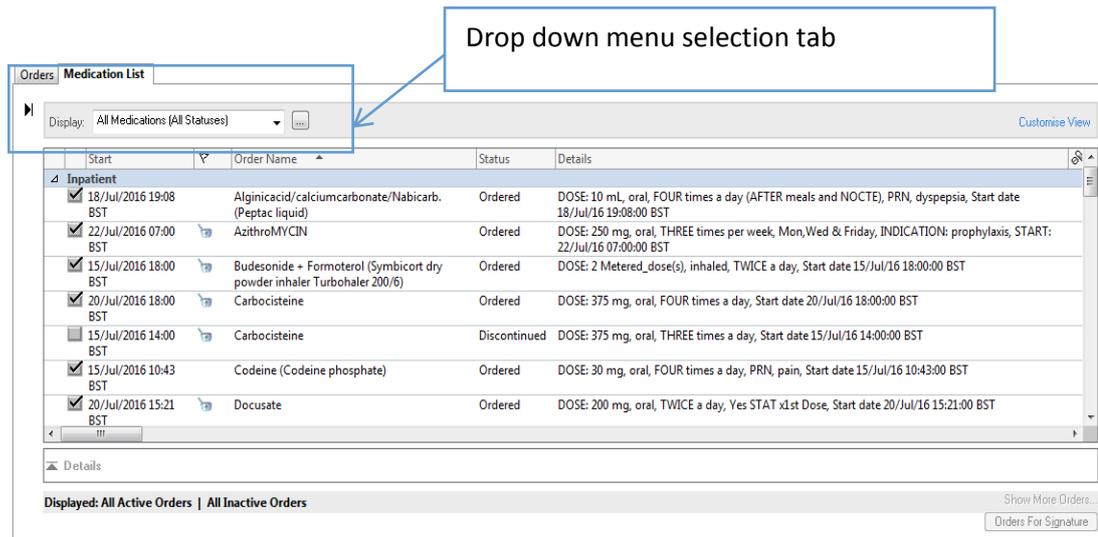
Figure 9: 'Medication List' set to show All Medications (All statuses)

When a medicine was prescribed for a patient, it appeared on the patient's active 'Medication List'. The medicine would normally remain on this list until it was actively stopped by the user *i.e.,* the order manually changed to 'discontinued'. However, some users assumed that orders, which were prescribed for only a finite period of time (*e.g.,* seven day course of antibiotics), would automatically drop off this list when the treatment course had ended. This was not the case. Instead the user was expected to go back into the patient's record and manually change the status (from active to discontinue). As a result, some medications on the 'all active medication' list were no longer being administered and, in some instances, the researcher observed how users could wrongly assume that the patient was still getting the drug when in fact they were not. One doctor explained how, on the previous paper-drug chart, it was more obvious to her when a medication had been discontinued as *"there [was] a line [drawn] through it" (P24; Doctor).*

This problem was also compounded by the fact that the 'Medication List' view did not display the stop date of the medication, and so it was difficult for the user to confirm whether a course of medication had actually been completed or not. To obtain this information, the user needed to click on either the 'Drug Chart' or 'Drug Summary' tabs, but these tabs were not always routinely reviewed during busy periods on the ward, as the researcher noted in her observations: *"some prescribers only accessed the Medication List [tab] and did not routinely view the Drug Chart or Drug Summary" (Observations Ward C.4) (Observations Ward D.4).* One of the senior pharmacists also described how doctors *"tend[ed] to use [the] 'Medication List' more and (…) [were] not so aware of the things that have been suspended*

or courses of antibiotics with a soft stop [a provisional stop date for a treatment course that may be extended depending on the patient's response]" (P30; Pharmacist). In one particular patient's case, the pharmacist explained how they had mistakenly gone without a medicine for a number of days.

> *"That was quite an error that you'd have an antibiotic course that had finished two or three days ago and the doctors still thought that somebody was on it and you go well "No, because that says the 15th December so they've not had it for six days" but it was still on the 'active medication list' so they still thought that the patient was on it." (P31; Pharmacist)*

A renal doctor also recalled how a patient had received a shorter course of antibiotics than intended *"because it had fallen off"* the medication list *(P26; Doctor)*. It was not obvious to her from the system that the stop-date for the shorter course had passed and they erroneously *"just assumed that that stop date had then been extended" (P26; Doctor).* The renal doctor explained how this could have had significant clinical consequences for this patient, who had a serious line infection and renal impairment. However, with the previous paper-based system, a circle was drawn around the last dose of the antibiotic in a 48 (or 72) hour time period, thus drawing attention to the fact that this medication needed to be reviewed or a note added on the prescription to review 48 hourly as part of the organisation's *"antibiotic stewardship"* policy *(P26; Doctor)*. This acted as an *aide memoire* for doctors, nurses or pharmacists during a daily drug round. Although the ePrescribing system did provide an equivalent reminder, in the form of a pop-up alert (see Figure 10), these alerts were only presented to the pharmacist or doctor when they first entered the patient's record and were not presented to nurses who were involved in administration and could have also prompted the doctor. One could question how useful the timing of these particular alerts were. Users were more likely to make decisions about a patient's medication when prescribing and with sight of their active medication list, rather than on first entry into the system.

Figure 10: Example of 'medication review alert'

Finally, some users recalled how dose times entered on the ePrescribing system, which did not fall within the usual drug administration rounds, were also more likely to be missed because they were less visible on the 'drug chart' and may only be seen with scrolling left and right across the screen. The risk was that the user could *"be scrolling down [the drug chart] and just see the twelve o'clock [medications] and then you've got to sometimes scroll across to see the two o'clock ones" (P10; Nurse).* (See Figure 11)

Figure 11: Drug Chart showing multiple columns between 9.00 and 11.30am increasing scrolling to see doses later in the day

7.1.2 Medication List Layout

The 'Medication List' was also potentially confusing for users because of how the medications were listed *i.e.,* alphabetically or chronologically. If alphabetically, using the 'All Medications (all statuses)' tab every aciclovir order prescribed for the patient during their current hospital visit would be listed one after the other, close to the top of the 'Medication List'. Although orders for the same drug could be conveniently grouped together in this way, one senior pharmacist explained how it was easy to get confused as *"you might see like ten lots of aciclovir instead of what they're actually on" (P6; Pharmacist).* It was likely that some of these orders had finished and the user had to concentrate on the dates to determine which orders were still active or discontinued. In contrast, a chronologically ordered list, more typical of a paper drug chart, presented *"the sort of sequence that it followed" (P2; Nurse)*, with only the most recent aciclovir order at the top and older orders appearing further down the list. This made it easier in a way to review a patient who was *"very sick"* or when there had *"been a complaint or an incident" (P2; Nurse)*. In reaching a compromise, one user felt it would be nice to *"have the important stuff at the top and then everything else alphabetically" (P20; Doctor).* This interviewee picked out antibiotics as one of the particular drugs that should be placed at the top so that *"you can see immediately what they're on, how long they've been on it, whether it needs stepped down to oral or changed" (P20; Doctor).* He also suggested putting anti-coagulants and steroids at the top: *"Anti-coagulants, so if they're on Warfarin or a NOAC [novel oral anticoagulant] even just to make sure they're on Tinz [tinzaparin]. And then things like steroids so you know what dose they're on and how long they've been on it. Like cardiac drugs maybe like digoxin or something like that" (P20; Doctor).* Another doctor who had also become accustomed to the alphabetical layout, *"expected to see aspirin at the top now and zopiclone at the bottom" (P24; Doctor)* questioned whether the "regular" and "when required" medications could be separated out.

7.2 Challenges related to viewing and documenting information about lab test results and medication in the system

7.2.1 Viewing test results in table format

Patient test results were often displayed in table format in the EHR system, with the name of the ordered test *e.g.,* Capillary Glucose (Point Of Care Test (POCT)) displayed down the left-hand column, and the date and time the results were issued e.g. 18/Jul/16 20:30

displayed horizontally across the top of the other columns (see Figure 12). It was possible for some blood tests *e.g.*, blood glucose levels, to be ordered for one patient multiple times in a day and the results would also appear on the same line, but with an additional column created. Thus, if a user wanted to view a particular test value issued on the 19/Jul/16 at 10:41, for example, they would need to scroll across to the right of the screen until they reached the column with the desired date and time.

Additional columns created for each lab test result

Results	18/Jul/16 20:30 BST	19/Jul/16 06:40 BST	19/Jul/16 08:04 BST	19/Jul/16 10:41 BST	20/Jul/16 06:09 BST	20/Jul/16 11:09 BST	20/Jul/16 20:53 BST	21/Jul/16 06:36 BST	21/Jul/16 06:43 BST	21/Jul/16 11:2 BST
Blood Gases and Point of Care										
Capillary Glucose (POCT)	7.0	5.1		5.0	5.0	5.3	5.8	4.8	7.4	5.8
General Haematology										
Haemoglobin			99							
Platelet Count			402							
Haematocrit			0.304							
RBC			3.49							
MCV			87.1							
MCH			28.4							
White Blood Count			6.40							
Neutrophil Count			2.80							
Lymphocyte Count			2.75							
Monocyte Count			0.57							
Eosinophil Count			0.20							
Basophil Count			0.08							
NRBC Count			0.00							
General Chemistry										
Sodium			137							
Potassium			4.6							

Figure 12: Blood test results in a table

The default setting for the table was to display the 100 most recent test results. One doctor explained how it "*sometimes cuts them [the blood test results] off the end and you have to specifically look back for them" (P20; Doctor).* For diabetic patients who had blood glucose readings taken quite frequently, *"the flowchart screen looked quite complicated, as each result generated an additional column for that day, therefore requiring more scrolling left and right to check each result. This appeared to frustrate the doctor." (Observations; Ward D.5)* One pharmacist also highlighted a further risk when scrolling down the different clinical tests ordered, as there were "*so many fine lines"* that she could easily "*misread by a line" (P23; Pharmacist).* This may explain why doctors were often observed *"holding a finger up onto the screen just below a particular test and scrolled the mouse left and right holding their finger as a focusing point to keep track of the particular reading of interest".(Observations; Ward D.5)* Furthermore, users did not have the option to view an individual blood test *e.g.,* creatinine, in a table on its own; one renal doctor felt that this made it more difficult to *"look at the trends in the blood tests and data" (P29; Doctor)* because the screen contained lots of

information. For some clinical tests *e.g.,* blood glucose levels, it was important to compare results that were taken at specific times in the day *i.e.,* a pre-breakfast result taken on one day with a pre-breakfast result taken on another day. Displaying the results vertically (see Figure 13) (rather than horizontally (as shown in Figure 12) would have allowed the user to compare results in this way. Consequently, one doctor felt it took *"longer to analyse"* blood test results presented horizontally and was more *"prone to mistakes" (P26; Doctor).* Another doctor shared a similar view explaining how it was *"cognitively a bit smoother" (P26; Doctor)* to interpret the information displayed in a paper insulin chart, as it included important contextual information about the dose time such as *"breakfasts in a vertical line, lunch and dinner" (P26; Doctor).*

All results taken at breakfast listed vertically aiding review of readings taken at similar times of the day *(compare like with like).*

Figure 13: Example of a typical paper blood glucose monitoring chart, showing results displayed with clear link to meal times

7.2.2 Viewing test results in a graphical format

Unlike viewing results in a table view however, it was possible for a user to view the results of an individual blood test in graphical format by ticking the box corresponding to the particular test (point 1, Figure 14), and then clicking on the graph icon in the top left-hand corner of the flowsheet screen (point 2, Figure 14).

Figure 14: Screenshot to show process for generating a graph for an individual blood test result

One doctor found this functionality (to generate graph) really useful as it enabled him to view a specific trend in one or multiple test results over time.

> *"You can tick sort of potassium, creatinine and urea and then you can graph them to show a trend, which is quite good so you can see their baseline and whether they're near it or above it, which is handy and I do really like that functionality because you can do that with things like [blood] sugar as well" (P20; Doctor).*

However, some users experienced challenges with using this functionality, such as some graphs lacking key information *e.g.,* dates, or the system failing to generate a graph if one particular test result value came back from the lab with an erroneous reading. This meant that the user had to *"find that error value [in the original table] and then get rid of it and then reselect all the ones and then graph it" (P29; Doctor),* which one renal registrar found

"silly [because] it should just miss [it] out, if there's any errors or different units it [the system] (…) it should just figure it out and then give you at least a rough idea so you can actually see a trend" (P29; Doctor). Furthermore, one user also described how she could not generate a graph beyond a certain date, which was challenging when the user wanted to extrapolate from the data and predict when a patient may need dialysis. Consequently, the user sometimes had to draw the graph by hand, which took additional time.

> *"There's some flaws in the system where sometimes if you go back to a certain date you can't actually plot out the graph and it is very difficult then, especially when we're predicting when someone is going to need dialysis so then we just have to sort of revert back to the paper system and do them by hand" (P29; Doctor).*

Further investigation of this revealed that for a short period of time the laboratory department were entering creatinine results into the system that were in a different format of measurement than those that they had used previously (*i.e.,* ml/min/1.73m^2 compared to ml/(min)/(1.73m^2)). The ePrescribing system therefore could not interpret these results, as all results should be in one standardised unit of measurement, and subsequently it was not possible to create a graph for patients who had a creatinine result reported during this period.

7.2.3 Difficulties documenting allergy information

Users liked the way that the patient's allergy status *e.g.,* amoxicillin: 'rash', was presented in the top left corner of the computer screen, although some felt that the colour was not *"really explicit" (P23; Pharmacist)* and the content rather restrictive. One doctor explained how she needed to click on the allergy box to bring up another screen with specific information about the particular allergy which felt a *"little bit tedious" (P8; Doctor).* The process of documenting an allergy was considered to be *"quite time consuming" (P25; Doctor)* with *"a lot of drop down boxes and a scroll through list with all the various different types of reactions" (P25; Doctor).* A pharmacy technician was observed *"trying to document 'wasp sting' as an allergy, but couldn't because this was not a coded option from which the user could select from" (Observations; Ward C.2,).* One doctor described how classifying the severity of the allergy on the system as either *"mild, moderate, [or] severe" (P7; Doctor)* was quite subjective and open to misinterpretation with some selecting 'severe' for *"like a rash or for angioedema and things like that" (P7; Doctor).* It was also unclear where free-text comments could be

entered and so some users found it frustrating that they could not *"document exactly what the allergy is [was]" (P12; Doctor).*

7.2.4 Difficulties viewing free-text medication-related information

Users were not required to provide a reason on the system for why they may have chosen to stop or temporarily suspend a medication *(e.g.,* an anti-hypertensive while the patient had acute kidney injury). However, this was important information for other healthcare professionals to know and one doctor felt that it should be made a mandatory field*: "you think "OK the drug was suspended and there wasn't a reason given and in the "see other comments" there is no comment so you just keep it suspended because you think that there may be a reason" (P11; Doctor).* Even with mandatory fields, another doctor admitted entering vague information like *"…'on-admission' or something" (P18; Doctor)* if he had either forgotten or did not know the reason for prescribing a particular drug. He recognised that this was his *"own shortcoming"* but explained how "*often they [the patient] don't know either" (P18; Doctor).*

One doctor also described how *"from a medical legal point of view"* it was important to document special instructions related to certain medicines in the system, such as *"increase the codeine dose from 30mg to 60mg if necessary for pain" (P12; Doctor).* However, users were sometimes concerned that information entered into a free-text box *e.g.,* special prescribing instructions, was not always clearly visible and did not *"actually show up really clearly to the nurses" (P12; Doctor),* thus could be easily ignored or overlooked. One specific case that the researcher observed was related to the administration of hydrocortisone to a patient with Addison's Disease. The nurse had either ignored or overlooked a free-text comment that had given specific information about the times at which the medication should be administered, and had consequently been administering the wrong amount of the medication at the wrong time.

"Hydrocortisone had been prescribed at 10mg twice daily, which defaulted to administration times at 7am and 6pm on the nurse's 'Drug Chart'. A further dose of 20mg once daily in the morning was also prescribed therefore on the 'Drug Chart', it appeared as though the nurse should administer 30mg (20mg + 10mg) at 7am and 10mg at 6pm. However, there was also a comment in a free text box on the 10mg twice daily order stating that 'these doses should be given twice daily at 13pm and 18pm' (i.e., the correct dose was 20mg at 7am, 10mg at 1pm and 18pm). The nurse however had ignored or overlooked this comment and thus had been administering the 1pm dose at the wrong time." (Observations; Ward A.1)

A doctor therefore suggested that these special instructions should be *"kind of red flagged to them [nurses], which [I think] would be an improvement" (P12; Doctor).* Free-text information was also used to supplement a prescription, when users felt that the basic order sentences that were available were either unsuitable or lacked certain information. For example, one pharmacist described how they used free-text to correct prescribing errors where they would annotate the incorrect order in the absence of the prescriber, with an accompanying free-text comment for the nurse administering the medication: *"'should be this, just give this'" (P6; Pharmacist).* Although the pharmacist admitted that it was *"not always the right thing to do"*, he explained how granting pharmacists *"more powers to modify or change things through the usual mechanisms [on the system] would be quite welcomed" (P6; Pharmacist).* However some pharmacists were also *"not sure how obvious"* their special instructions were *"for either the prescriber or the person administering the medication" (P19; Pharmacist)* and remarked that such information was *"probably more visually apparent"* on a paper drug chart. Furthermore, attempts to make a special instruction more prominent by putting *"stars and quotation marks and other things" around it* were often not successful as it *"quite often [gets] buried in a whole bunch of other text on the screen" (P19; Pharmacist).* One pharmacist suggested that the special instruction field should appear *"in a different colour on the drug chart (…) [to] make it stand out" (P27; Pharmacist).*

7.2.5 System restrictions in the free-text comments field.

The discharge letter contained a free-text comments field, which also posed a particular challenge for some users. One doctor explained how only a fixed number of characters could be entered in this free-text field, and this was often not enough space to explain the multiple

changes that were made to a patient's medications while they were an inpatient. In one particular case, the user highlighted how the system had *"cut the last five things off" (P26; Doctor)* so she had to spend time re-structuring the notes to *"put all the essential things on and abbreviate and fit them in" (P26; Doctor).* Similarly, another doctor also discovered by chance that after logging in, doctors and nurses saw different amounts of information contained in the free-text field on the hospital system in their own screen view. For example, the free-text field on the nurse *'Drug Chart'* view was restricted to *"maybe like 12 lines or something, so if you go past that [prescribe warfarin doses past the 12-lines] they [the nurses] can't actually see it" (P24; Doctor).* Therefore, although a dose may be documented and clear on the prescriber's ordering screen, this doctor found that *"often they [the nurse] will ring you on call and say 'it's [warfarin] (has) not been prescribed' and it has, it's there, and we realise[d] actually you can type lots of it down, but when the nurses look at it there's only so many lines down they can actually see" (P24; Doctor),* which was ultimately confusing.

Another doctor found it difficult to know where to add the quantity of a controlled drug (legal requirement) in words and figures, as it could be entered in a range of different places where *"sometimes it comes up on the print out and sometimes it doesn't" (P25; Doctor)* Worried that it might not appear, she resorted to *copy[ing] and paste[ing] the same information into four places [on the system] and hope[d] it comes out in one of them" (P25; Doctor).*

> *"There is a little tab saying 'Supply' but it won't let you write it in words and figures there, so then there's a tab below saying 'Supply words and figures' so you write it there and sometimes it comes up on the print out and sometimes it doesn't, so then you can go to 'Special instructions' and write it there as well. Sometimes that comes up and sometimes it doesn't, so then there's a different tab across the top called 'Comments' that you can then write it again and that usually comes up" (P25; Doctor).*

7.3   The use and meaning of symbols

When the user first logs onto the system and selects a particular ward, they are presented with a patient list. The first column on this list, entitled "VIP code" (see Figure 15), sometimes contained a 'star' icon next to a patient's name. This 'star icon' symbolised that important information had been included on the system about this specific patient, such as whether they had a *Methicillin Resistant Staphylococcus aureus* (MRSA) infection.

Figure 15: Patient List with star icon

One pharmacist described the *"little star"* icon as *"not that obvious"* and *"not something that you [would] always check" (P6; Pharmacist).* Another pharmacist echoed this by explaining how the little icon failed to stand out to nurses during a *"busy drug round",* thus many nurses did not "*click on it, to read it" (P27; Pharmacist).* A junior doctor described the additional steps that he needed to follow in order to view this information: *"you've got to go into the left-hand menu and go to patient information or alerts or something and then only then does it tell you" (P15; Doctor).* It was not clear to the user that this information was actually contained in the 'Problems and Diagnoses' tab, and may have been more intuitive to just 'hover' over the star icon to find out the important information.

Some users also found it difficult to know how to change the default order times for medications when they were prescribing because the tab that they needed to click on did not include a symbol or icon that resembled 'administration times' or 'modifying a prescription'. One doctor described how he had not understood that he needed to click on a *"grey box (...) with three full stops in it" (P17; Doctor),* which would then "*bring[s] up [options] to change the administration times" (P17; Doctor)* (see figure 16). Thus, the process of modifying a dose administration time was therefore not considered to be straightforward and one doctor commented on how he "*wouldn't have known how to do [it] if I[he] hadn't had the training" (P17; Doctor).*

Figure 16: Modify Prescription Icon with 'three full stops'

7.4   Challenges with using disparate systems

The so called 'discharge system' was used to prepare a discharge prescription and letter for a patient and was a different stand-alone system to that used to prescribe medicines for the patient while they were an inpatient (*i.e.,* hospital system). Thus, if a doctor had documented a reason why a medication was suspended or discontinued on the hospital system in free text, this information did not automatically transfer over to the discharge system. Furthermore, some orders such as miscellaneous items that were entered in the free-text box (either on their own or selected with other medications in the 'Medication List'*)* and combination products, such as Co-amoxiclav (clavulanic acid and amoxicillin) or Seretide (fluticasone and salmeterol) also did not automatically transfer over. One doctor found it *"quite frustrating"* (P12;Doctor), as he had to open up a small view of each system on his computer *"to get a side by side sort of comparison of documented meds and discharge medications or what they were on (…) and [click] flick back and forth"* between them *(P12; Doctor).* Another junior doctor also explained how she had missed these miscellaneous item(s) off the discharge prescription a couple of times "*because it doesn't transfer" (P16; Doctor).* A senior pharmacist explained how the "*prescriber has to be made aware that they need to re-prescribe it as a discharge order" (P30; Pharmacist),* thus introducing an additional step in the discharge prescription issuing process and also introduced the risk that the free-text information about why changes were made, would not get documented on the discharge prescription due to a lack of time. The pharmacist often had to *"go in and add more detail (…) in the special instructions [field]" (P31; Pharmacist)* such as the brand or formulation of the inhaler *e.g.,* Evohaler, or include combination products that had been accidently missed off the patient's discharge prescription.

7.5   Workarounds

As a result of challenges with the system design, users developed workarounds so that they could make certain processes either easier or, in their view, safer. Examples included, working around mandatory functions in the system that were seen to have imposed unnecessary barriers to the workflow process.

7.5.1   Mandatory functions

The system had a mandatory field, which asked users whether they had contacted the anticoagulant service to book a suitable follow-up appointment, and requested that the

specific time and date be entered on the system before a patient was discharged. However, prescribers did not always know this information at the point of completing the necessary discharge paperwork as they *"couldn't make a community warfarin appointment until the day they were going [home]" (P12; Doctor)* and the *"warfarin service works by ringing you back [with a time and date]" (P13; Doctor).* Therefore, some users admitted that they would *"write what I am intending to do for the warfarin, so if I want them to have a warfarin follow up appointment on the Wednesday, even if I don't have one, I'll say that [I do]" (P13; Doctor).* One doctor felt it was better to add an 'intended' date because otherwise the system would *"halt a discharge and upset[s] nurses and upset[s] patients so I don't find that helpful" (P13; Doctor).* Another doctor explained how he would *"effectively lie on the computer"* by saying that he had *"booked the appointment" (P12; Doctor)* but just needed to remember to do it. Another doctor described how she *"always managed to get an appointment"* when she said she would, but *"would always go back and change it [on the system]" (P13; Doctor)* if on the rare occasion this was not possible. This clearly created a risk that patients might have received incorrect information on their discharge prescription and subsequently miss out on post-admission monitoring for a high-risk medication. Reflecting on the discharge prescribing process overall, one doctor described the system as *"good in the way that it's prompting you to make sure everything is done for the patient before they go" (P12; Doctor)* but it was possibly *"too specific" (P12; Doctor).*

7.5.2   Improve visibility

If a drug was not administered, the administration box on the system would automatically turn from 'blue' (the dose was due) to 'red' *(i.e.,* the dose was overdue) after one hour. If the nurse selected a reason from the drop-down menu *e.g.,* 'medication not available' for why the drug was not given, the administration box would turn from 'blue' to 'grey' (the order was completed) (See Figure 17) However, one nurse acknowledged how she did not usually click the 'not given' reason from the drop-down menu, so that the dose administration box would remain blue or red, and *"indicate that it [the dose] was overdue or still needed to be given. This, acted as a prompt that the dose should be given when the stock was obtained" (Observations; D.3).* If the nurse had signed the dose off as 'not given', the dose would not appear on the nurse's drug chart to be given until the following day and the patient may unnecessarily miss a dose of their medication. Thus, the colour of the administration box acted as a powerful prompt for nurses, who were observed during a drug administration

round specifically *"scroll[ing] up and down the Drug Chart record in order to identify any red or blue boxes, which signified doses that were due to be given"* (Observations; Ward B.2).

Medications	12/Sep/17 23:32 BST	13/Sep/17 07:00 BST	13/Sep/17 08:54 BST	13/Sep/17 09:03 BST	13/Sep/17 09:04 BST	13/Sep/17 09:05 BST	13/Sep/17 11:22 BST	13/Sep/17 12:00 BST
ibuprofen					400 mg NG Auth			
Pt Self Administer								
Lansoprazole DOSE: 30 mg, oral, DAILY, Indication: reflux, Start date 13/Sep/17 07:00:00 BST								
lansoprazole						30 mg NG Auth		
Pt Self Administer								
Morphine (Morphine (MST Continus) modified release tablets… DOSE: 20 mg, oral, TWICE a day, Start date 12/Sep/17 20:00:00 BST								
morphine				2.. mg oral Auth				
Paracetamol (Paracetamol oral suspension sugar free) DOSE: 1 gram, oral, FOUR times a day, Start date 12/Sep/17 18:00:00 BST, Each dose must be 4 to 6 hours apart.		1 gram Last given: 12/Sep/2017 23:28 BST						1 gram Last given: 12/Sep/2017 23:28 BST
Paracetamol								
Pt Self Administer								
PRN								
PRN **Cyclizine (Cyclizine Injection)** DOSE: 50 mg, intravenous, THREE times a day, PRN, nausea/vomiting, Start date 12/Sep/17 17:58:00 BST							50 mg Not previously given	
cyclizine								
Pt Self Administer								
PRN **Misc Prescription (Caphosol Mouthwash)** DOSE: 1 Metered_dose(s), topical, Symptom Relief, PRN, Mucositis, Start date 12/Sep/17 17:58:00 BST, Combine both solutins and use as a mouthwash.							Metered_dose(s Not previously given	
Misc Prescription								
Pt Self Administer								

Figure 17: Drug Chart showing overdue (red), administered (grey) and to be given (blue) doses.

7.5.3   Clarification or correction of prescribing errors

One pharmacist recalled how *"if a doctor prescribed the wrong Seretide inhaler [on the previous paper drug chart] a pharmacist would just change that"* (P6; Pharmacist). However, it was not possible to change the inhaler device *"from an Accuhaler to an Evohaler"* (P6; Pharmacist) on the new ePrescribing system and so some users used a workaround to save time or if the prescriber was not available. This involved signing into the pharmacist verification system *"and instead of clicking 'accept' you can click 'verify', which will let you modify just about anything with the drug within reason"* (P6; Pharmacist). Indeed, the pharmacist commented on how this *"would be completely illegal"* (P6; Pharmacist). This pharmacist added that making such changes was reserved for particular errors related to *"chang[ing] the formulation"* (P6; Pharmacist,) rather than *"chang[ing] the dose […] because that is just not correct"* (P6; Pharmacist).

Complex intravenous antibiotic regimens were also commonly associated with prescribing errors (*e.g.,* omission of the appropriate reconstitution solution and line flushes) at the discharge stage, due to the need to prescribe intravenous medications and suitable diluents

for home use. In order to overcome this frequently occurring prescribing error on one ward *"one of the specialist nurses within respiratory, actually documents antibiotic discharge prescriptions for his patients with bronchiectasis"* into the *"documented medications facility within [the ePrescribing system]" (P31; Pharmacist).* The doctor then just had to right click and 'convert' those items from a documented medication into an active 'inpatient order' or into an discharge prescription order *"so that they don't get missed off" (P31; Pharmacist).* This was considered to be a good *"way of reducing the errors" (P31; Pharmacist)* and also saved time because any errors made at the prescribing stage had a knock on effect for the dispensing stage because home-intravenous medications were *"quite long and complicated things for us [the pharmacy] to dispense" (P31; Pharmacist).*

7.5.4 Prescribing IV infusions and emergency medication on paper drug charts

It was possible to order IV infusions (*e.g.,* for *magnesium or insulin-dextrose)* on the ePrescribing system, yet some users felt *"more comfortable" (P24; Doctor)* prescribing these on paper*.* This appeared to be related to a lack of familiarity with how to prescribe infusions on the system, in particular when entering *"the rate in and drugs",* which this doctor felt was just *"easier to write" (P24; Doctor)* on paper. Some users worried that the prescribing guidance entered onto the electronic system, could be interpreted incorrectly by nursing staff and consequently, placed some orders both on paper and electronically. One doctor remarked how they would *"automatically just write it [the IV infusion] on a [paper] drug chart because it's a fluid" (P24; Doctor),* even though *"some of the nurses aren't [were not] happy" (P24; Doctor)* with them doing this.

Furthermore, if a medication *e.g.,* prasugrel for a patient with a myocardial infarction, needed to be ordered in an emergency, some doctors would prescribe the order on a *"a green photocopied front of the old prescriptions sheet the old drug kardex" (P2; Nurse)* instead of *"log[ging] in and out" (P2; Nurse)* of the system. This nurse also described problems with administering medication in an emergency such as locating a computer, *"find[ing] a one that's working and that's actually charged up, [and] find[ing] a one that will accept your card",* which *"if you're in a hurry and you need to do something"* may not be practical *(P2; Nurse).* There were also instances where patients *"come onto the ward who don't necessarily get admitted [onto the system]" (P24; Doctor*) for example to receive a short procedure or test. As the patient was technically not an inpatient, the nurse or doctor could not 'admit' them onto the system, which meant that although the clinician could *"order*

bloods [but] you can't really do anything else on the system" (P24; Doctor) and if the patient needed a *"medication or something (…) you have to just do it on a paper one [chart]" (P24; Doctor).*

7.6   Chapter Summary

This chapter explored the various key challenges facing users when using specific design features of the system. Firstly, the researcher discussed the specific challenges of the medication list, including those relating to how medications were displayed and the dangers posed by a lack of stop dates on the medication list view. There were mixed views about the order in which the 'Medication List' should be presented, with some users displaying the list alphabetically, rather than chronologically, which in turn made it difficult to understand the sequence of the prescribed drugs. Others found the alphabetical list useful, as they expected to see 'Aspirin', for example, close to the top.

The researcher also described the challenges of viewing test results in both table and graphical formats, including the amount of scrolling that was required to view test results over time in a table format and the inability to generate a graph if there was an error with an individual test result. Users described how it was difficult to interpret patient's blood glucose readings over time when they were presented horizontally in chronological order, as it made it challenging to compare the time of day the test was taken *e.g.,* a pre-breakfast reading, with another pre-breakfast reading to identify a trend.

A number of challenges related to viewing and documenting information on the system were discussed, including more specifically a patient's allergies and medication-related information, such as the reason why a medication had been suspended. It was also apparent that some information that was documented by a doctor in the 'special comments' field was not always visible to the nurse, and therefore important information could be missed. The researcher also identified how restrictions in some free-text fields meant that some information could be 'cut off' and not visible to other users.

This chapter also described some of the difficulties users had with understanding the use and meaning of symbols. For instance the use of a small star to indicate that the patient had MRSA was not that obvious, and some symbols did not resemble their intended meaning. The use of disparate systems and issues related to information not been reliably transferred between the hospital system and the discharge system appeared to frustrate users. Finally,

this chapter highlighted some of the workarounds users have taken in order to carry out certain processes either more quickly to overcome specific limitations of the system's design.

In order to address some of the challenges posed by the specific design features and limitations of the system, users and the hospital's system development team customised the ePrescribing system in a number of ways. The next chapter describes the customisations made to three key features in the system: (1) the medication list, (2) insulin ePrescribing functionality, and (3) the pharmacy task list.

Chapter 8

What are the benefits and challenges of customising a commercial electronic prescribing system?

The commercial ePrescribing system in place at the study site had been internally customised after its initial implementation. Some of these changes were made by users, in order to overcome some of the challenges discussed in the previous chapter. Similarly, the hospital's system development team made changes to the system in order to improve patient safety and efficiency. This chapter discusses some of the benefits and challenges of customising a commercial system focusing on three key areas: (1) medication and patient lists, (2) insulin ePrescribing functionality, and a (3) pharmacy task list, based on the findings from the main study.

8.1 The benefits and challenges for users when customising the Medication and Patient Lists.

8.1.1 Customising the Medication List

As discussed in chapter 7, users could not see certain pieces of information on the 'Medication List' tab view (*e.g.,* medication stop date) unless they scrolled left or right across the screen. Some users therefore customised their 'Medication List' tab view in order to be able to see this information. However, not all participants were aware that this customisation could be done, with one junior doctor explaining how he *"didn't even see the customise view button until somebody [in microbiology] showed it"* to him *(P20; Doctor).* One senior pharmacist customised the 'Medication List' *tab view,* so that she could see the "*start date, stop date, [and] the drug" (P23; Pharmacist).* However, this came at a cost, as information (such as the name of the prescriber) was now out of her immediate view. In contrast, another senior pharmacist chose to prioritise the name of the prescriber as she felt that it was more important to be able to quickly identify and contact them if there was an issue with a prescribed medicine.

> *"No, the thing that I do have [on the 'Medication List'] though is the person that prescribed it. If I want to speak to somebody about it I know who to speak to. I think*

I've got the start and the stop date after the drug name so I might have to scroll to the right in order to find it" (P30; Pharmacist).

This pharmacist also customised the layout of the screen such that ordered (active) medicines were at the top and those now completed (inactive) were at the bottom (See Figure 18). In her opinion, this made the list "*easier to scan through" (P30; Pharmacist)*.
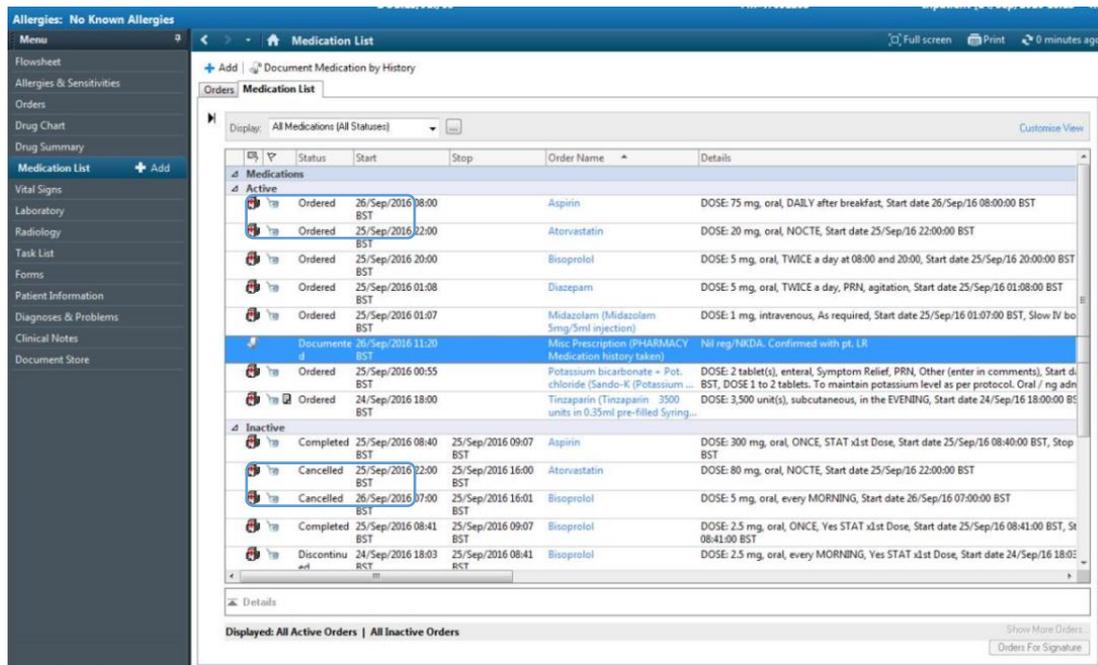
Figure 18: Customised 'Medication List' tab view, showing ordered medicines at the top (active) and those completed (inactive) lower down.

It was possible for the layout of users' screens to differ and the researcher queried what impact this might have when users were looking at the screen *"using another user's log-in details" (Observations; Ward B.3)*.One doctor explained how *"everyone looks on mine [my screen] and says 'oh that looks wrong' so I don't quite know what I've done" (P13; Doctor)*. Some users found the font size on the 'computer-on-wheels' devices *"quite small" (P22; Doctor)* and increased it to make it more visible. However, one nurse described how increasing the font size meant that you now had to scroll more, which resulted in her *"missing drugs and doses and stuff like that so I [she] just went back to the generic setting" (P4; Nurse)*.

8.1.2 Customising the patient list

Some users customised their 'Patient List' view tab in such a way as to group patients either by ward (*e.g.,* medical ward 1), or type of wards (*e.g.,* all surgical wards), or the particular

bays within a ward (*e.g.,* bays 1 and 2) (See figure 19). One nurse described how she had "*split the ward into two*" *(P9; Nurse)* on the system so that she could concentrate on one section at a time. She also encouraged other nurses to do the same as she felt it helped her to "*minimise error*" *(P9; Nurse).* One of the doctors explained how this customisation had also helped him locate information more quickly: "*if [I] need to know whose patients and things and who to call, it's quite quick reference*" *(P17; Doctor).*
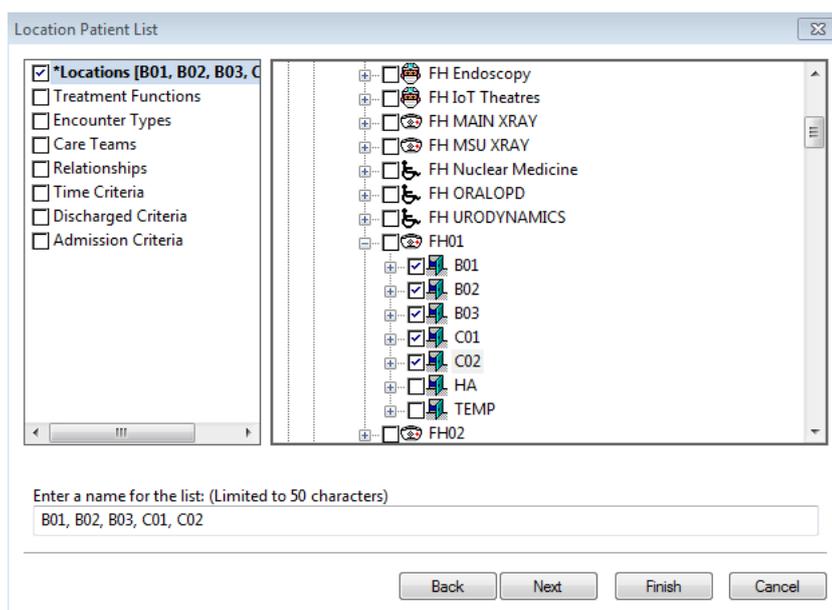
Figure 19: Selection of individual wards and bays that can be displayed on the Patient List.

However, the process of customising the 'Patient List' was not simple and was described by one user as "a nightmare" (*P15; Doctor*). He found it difficult to locate the *"very small little drop down box"* that was required before he then "*select[ed] like location and then like encounter types [inpatient/outpatient]*" *(P15; Doctor).* He described how if you selected the specific ward you wanted, then the danger was that every patient who had ever been on that ward appeared. This made it very difficult for him to find any of his patients; consequently he viewed the system as *"backward" (P15; Doctor).*

8.2 The introduction of Insulin ePrescribing functionality

8.2.1 Changes to how insulin was prescribed and monitored

On July 14th 2015, 'Insulin ePrescribing' was introduced at the research site; this introduced some changes related to the way insulin was prescribed and monitored. The first change was

that insulin could now be prescribed electronically *"on [the system] from anywhere in the hospital" (P16; Doctor).* This was viewed as an improvement, as previously insulin was prescribed on a paper drug chart. Secondly, a continuous prescription could now be generated for the patient on admission, with the same 'default' dose given every day, regardless of the patient's blood glucose levels or clinical condition. This was in contrast to the previous prescribing process where, "a *day's worth of insulin [would typically be prescribed] and then they [the prescriber] would prescribe it again the following day and again the following day" (P30; Pharmacist).* Thus, the patient's insulin was reviewed on a daily basis, with dosage adjustments made according to the patient's clinical condition. However, one pharmacist described a possible issue related to the frequency of medication reviews noting that "*the risk now is [that] they forget to review it [insulin] and the patient gets the dose anyway and that might not be appropriate" (P30; Pharmacist).* However, during the development of insulin ePrescribing, the system development team had sought the input of a local diabetologist who felt that it would be "*worse if a patient doesn't get their insulin, than if they get a dose of insulin that is maybe a couple of units more or less than what it should be" (P32; Pharmacist)* justifying the decision to use a default daily dose of insulin. The input of the diabetologist was considered important by a pharmacist who was involved with the development of the insulin ePrescribing functionality, as they were able to reassure prescribers who resisted using the system that "*you've gone through that [development] process and they go 'oh...good point'" (P32; Pharmacist).*

Thirdly, insulin had to now be prescribed using an order set (Figure 20), which was described by one doctor as "a bit faffy" because they had *"to like scroll down, find the insulin type that you want, tick it and then you click OK and then it opens up a separate page where you've got to type how many like doses you want" (P16; Doctor).*
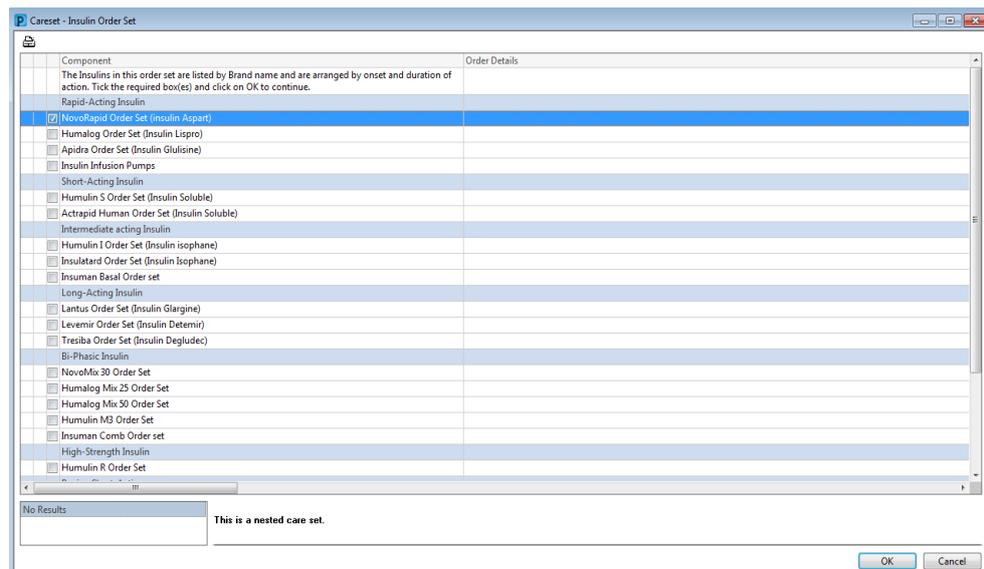
Figure 20: Insulin Order Set

However, this also meant that pharmacy staff could not document insulin in the electronic 'Documented Medications' tab (the electronic medication history) as it was part of an order set and instead now needed to be recorded "*as a miscellaneous prescription*" (*P31; Pharmacist)*. This involved typing in the specific insulin product and doses as free-text, which was more error prone. The insulin product *e.g.,* Humulin M3 would also appear under 'M' [for Miscellaneous] on the *'All Active Medication List'*. In contrast, if this had been prescribed by selecting the structured option from the order set, Humulin M3 would appear under 'H' on the same list. This was potentially confusing for users as all of the insulin orders may be in different places.

8.2.2   Changes to how blood glucose results were recorded

The 'Glucose Monitoring View' was developed by the local system development team and displayed all anti-diabetic medicines (*e.g.,* metformin) together with (a) any other related medicines (*e.g.,* steroids) that could affect glycaemic control, and (b) relevant tests (*e.g.,* blood glucose readings) on the same screen. This was considered to be *"quite handy" (P20; Doctor)* by one junior doctor. However, it was possible that other clinicians may have been unaware of this screen view, as they needed to first select 'Glucose Monitoring View' from a drop down list within the 'Drug Chart' view (see Figure 21).

Figure 21: Medication monitoring view, with options to select view of the Glucose Monitoring View, Coagulation View, and General Lab Results

The blood glucose readings themselves were entered on the system, either manually by a nurse or via Bluetooth from a blood glucose reader (which was linked to the system). This was considered by some as being helpful as *"you can track the BM's (blood glucose monitoring) […] against the insulin doses"* and get *"a running log basically of exactly what they had" (P23, Pharmacist)* all from within the same screen. Indeed, one junior doctor felt that insulin ePrescribing was more time efficient than the handwritten alternative, as *"you can just sit at a computer" (P16; Doctor)* in one location and alter the dose, rather than have to visit each ward to make the change for all patients.

However, there were some limitations. For example, one pharmacist expressed concerns about the ease of remote access and how some important information, such as whether *"the patient [had] eaten, [or were] they nil by mouth" (P23; Pharmacist)* might not be on the system. There was therefore *"a danger of [prescribers] just looking at a computer screen seeing the result and going "oh right yeah the BM is high let's give them something", but you don't actually know what's going on" (P23; Pharmacist)*. One junior doctor also acknowledged this risk, but felt that *"most of the information you can get over the phone" (P16; Doctor).* Furthermore, it was suggested that blood glucose results were not always available in 'real-time, which could be dangerous if users made decisions based on outdated information, whilst working remotely.

"And I don't know as well whether there's a bit of a delay or what the delay is in-between taking the reading and it uploading onto the system as well" (P30; Pharmacist).

Also, when blood glucose results were documented on paper, the staff member responsible *e.g.,* nurse or healthcare assistant, *"were very used to measuring the blood glucose, looking at the result, writing the result down and then acting on it if they needed to" (P30; Pharmacist).* One pharmacist believed that these nurses or healthcare assistants were also more aware that they had documented a clinically relevant result onto the paper chart or if a trend was emerging than when results where entered automatically. She also added that *"because the 'writing-it-down' step has [had now] been taken away, the 'acting-on-it' step seems to sometimes not happen"* (P30; Pharmacist). She also hypothesised that certain staff, like healthcare assistants, *"might not be as trained to recognise when something isn't quite right" (P30; Pharmacist).*

Finally, the system could not process blood-glucose results directly from a patient's own monitoring device (as opposed to the hospital Bluetooth devices) so the result *"wouldn't automatically go on [the system]" (P30; Pharmacist)*. Instead, nurses were supposed *"to check with the patient how many units they did actually self-administer and then retrospectively upload that data"* (P30; Pharmacist). This pharmacist questioned the workings of this new process as health care professionals (nurses or healthcare assistants) relied on the patient to accurately recall the right result(s) and input these correctly.

8.3 The benefits and limitations of an internally developed pharmacy task list

The system development team produced a 'pharmacy task list' in the ePrescribing system (see Figure 22). This was a list of 'high priority' tasks that needed to be performed for certain patients within a selected ward or clinical area. Tasks were automatically added to the list, like when a 'high-risk' medication such as warfarin, insulin or an antiepileptic was prescribed. A user could also create a task that prompted another member of staff to review a patient if they had concerns. For example, one senior pharmacist noticed how some of the junior pharmacists had set up tasks related to *"U&E triggers and that kind of thing so (…) [there are] a lot of different ways to prioritise who you see first" (P27; Pharmacist).* As all members of the pharmacy team (*i.e.,* pharmacists, pharmacy technicians and pharmacy assistants) could access the task list, it also served as a communication tool between staff to provide

information within the system. For example, staff working within a clinical area could create "*clinical handover[s] or a pharmacy supply handover[s]*" *(P21; Pharmacist)* to advise their colleagues that a patient had certain administration requirements, which would be visible, even if the patient had been transferred between wards. Another pharmacist described how the task list was beneficial because he could "*see any discharges there, any medication histories needing doing, any urgent handovers*" *(P6; Pharmacist)*. He found this particularly valuable when he was "*the only pharmacist for the directorate and because of sicknesses, absences, holidays, meetings, (…) [he was responsible for] 7 or 8 wards*" *(P6; Pharmacist)*. This was echoed by a second pharmacist who explained how he would have never known if a patient was on a 'high risk' medication unless he "*was physically on the ward checking [their] medical notes*" *(P21; Pharmacist)* and so he "*would have to spend a couple of hours on such and such ward and another couple of hours on that ward*" *(P21; Pharmacist).* High risk patients, such as those on lithium or phenytoin, were now easier to identify using the task list, which meant that he was potentially able to resolve issues quicker and possibly care for more patients. Users were also able to add tasks manually, thus helping to "*target [their] workload a little bit better*" *(P30; Pharmacist).*

	Location/Room/Bed	Mnemonic	Order Details	Order Status
✔	FH18 / B02 / 06	Pharmacy Medication History Required	Order dt:tm: 14/Jul/16 13:33:29 BST New admission	Completed
	FH18 / B02 / 06	Pharmacy Handover (Medium Priority Pharmacy Clinical Handover)	Order dt:tm: 18/Jul/16 13:31:00 BST, Details: T3 review, 22/Jul/16 08:30:00 BST	Ordered
	FH18 / B02 / 06	Pharmacy Handover (High Priority Pharmacy Clinical Handover)	Order dt:tm: 18/Jul/16 13:35:00 BST, Details: ?intentional dose increase MST?, 19/Jul/16 08:30:00 …	Ordered
	FH18 / B03 / 01	Pharmacy Handover (High Risk Drug Monitoring)	Order dt:tm: 23/Jun/16 16:59:00 BST Warfarin - withheld 23/6 on tinz	Ordered
✔	FH18 / B03 / 02	Pharmacy Medication History Required	Order dt:tm: 05/Jul/16 13:06:22 BST New admission	Completed
✔	FH18 / B03 / 02	Warfarin - Pharmacy Review	Order dt:tm: 05/Jul/16 17:35:40 BST Warfarin Prescription	Completed
✔	FH18 / B03 / 02	Pharmacy Handover (High Priority Pharmacy Clinical Handover)	Order dt:tm: 05/Jul/16 18:35:00 BST History done - please review and verify when possible. Some pre-admission meds have been pre…	Completed
	FH18 / B03 / 02	Pharmacy Handover (High Risk Drug Monitoring)	Order dt:tm: 05/Jul/16 18:35:00 BST WARFARIN - monitor INR 12/7/2016	Ordered
✔	FH18 / B03 / 03	Pharmacy Medication History Required	Order dt:tm: 12/Jul/16 18:26:28 BST New admission	Completed
✔	FH18 / B03 / 03	Pharmacy Handover (Medium Priority Pharmacy Clinical Handover)	Order dt:tm: 13/Jul/16 16:06:00 BST Patient recently discharged from orthopedics on 4500 units daily TINZAPARIN on discharge. Una…	Completed
✔	FH18 / B03 / 03	Pharmacy Handover (Medium Priority Pharmacy Clinical Handover)	Order dt:tm: 13/Jul/16 16:06:00 BST Medication history completed - to be type 3 reviewed.	Completed
	FH18 / B03 / 03	Antipsychotic medication review	Order dt:tm: 15/Jul/16 16:45:59 BST, Details: Initial review Haloperidol	Ordered
✔	FH18 / B03 / 03	TTO's for Discharge	19/Jul/16 10:04:00 BST, Items to dispense: Please dispense 14 days, Disch. Dt +Tm 20/Jul/16 14:00…	Completed
	FH18 / B03 / 04	Pharmacy Medication History Required	Order dt:tm: 17/Jul/16 00:52:42 BST	Completed

Figure 22: Example of the Pharmacy Task List

In contrast, one pharmacist described how the task list had "*indirectly increased our [the pharmacy team's] workload*" (P21; Pharmacist) as he "*would have never been asked to cover more than one ward in the past*" (P21; Pharmacist).

Users also discussed some further limitations of the pharmacy task list. Firstly, it could not prioritise high risk patients, but only signalled if they were on high risk drugs. For example, the system only informed the pharmacist "*if phenytoin or carbamazepine has been prescribed*", and not "*if there's an epileptic patient on the ward*" (P21; Pharmacist). One pharmacist felt that it was more prudent if she saw a patient on a "high dose opiate" *(P27; Pharmacist)*, than on the high risk drug carbamazepine, even though no alert was triggered for the former drug. The system, in this case would be unable to provide information that would allow the pharmacist to distinguish between whether the user was taking carbamazepine for pain, or for the high risk indication epilepsy, contributing to this ambiguity.

> *"It [the task list] triggers an alert for carbamazepine and most patients that are on carbamazepine, certainly in my experience, are on it for pain and whilst they need seeing, while I'm doing that I'm missing somebody that's been admitted on a high dose opiate" (P27; Pharmacist).*

Secondly, and related to this, if a high risk drug *e.g.,* insulin had not been prescribed for a diabetic patient, perhaps because it had been accidently missed on admission, the pharmacy task list would also not be able to *"flag those things up" (P30; Pharmacist).*

> *"The thing that it can't do is, so it can't identify when a patient who normally is on insulin hasn't had their insulin prescribed and that I think is a bit of a risk so we're very pro-active about targeting high risk things that have been prescribed, but we probably end up missing more things that aren't prescribed appropriately because it can't flag those things up"* (P30; Pharmacist).

To mitigate these two limitations, the pharmacy team introduced a new service whereby the pharmacy technician who performed a medicines reconciliation review (the process of performing medication history and supplying any medications) "*assign[ed] a priority level to the patient based on their clinical judgement" (Observation; Ward C.2);* this was entered into the task list in the system. Therefore, *"patients who had not been prescribed critical*

medicines would be classified as high risk" (Observation; Ward C.2), as would patients with complex health needs.

A third limitation of the pharmacy task list was that not all medicines perceived as high risk were actually added to the list. One pharmacist noted how *"we've got warfarin [but] we don't have [triggers for] any other NOACs [novel [Direct] oral anticoagulants]" (P27; Pharmacist)* and another pharmacist noticed how *"some of the antiepileptics do not necessarily create an alert" (P21; Pharmacist),* which appeared to frustrate them, as they thought that *"if we create[d] an alert about phenytoin, I don't see why we shouldn't do sodium valproate or topiramate" (P21; Pharmacist).*

A fourth limitation of the pharmacy task list was that it also did not consider external factors, such as the type or speciality of the ward. For example, a cardiology pharmacist explained how her ward had a high patient turnover, which shifted the priority towards managing those patients who had either been newly admitted or were being discharged, rather than reviewing longer-stay patients. She acknowledged that although her workload was guided, in part, by the task list*,* she also felt that it was important to see*, "what's been written on the ward board, nursing staff coming and saying that there's a discharge or [Name] phoning me to say they've just put another discharge on"* (*P31, Pharmacist).* Another pharmacist explained how you *"just have [to] use your own judgement" (P23; Pharmacist)* because "*the system is never going to be able to completely recognise"* the different priorities and urgency of some pharmaceutical care issues.

Some pharmacists therefore kept a paper 'to-do' list. One pharmacist checked the *"electronic task list and then printed a patient list, which he would annotate with notes such as 'DHx[drug history] to do' and information about drugs that required monitoring/or were in need of a review and this was then used as his 'working task list'" (Observations; Ward B.1).* The paper task list was useful for this pharmacist because he could add tasks that he considered important (albeit in paper) but were perhaps not classed or detected as 'high-risk' by the system. Examples included *"GKI [Glucose, Potassium, Insulin Infusion] and heparin infusions, which may still be documented on paper" (Observations; Ward B.1).*

Another senior pharmacist commented that *"when she was doing her surgical rotation she did not use a paper list as the turnover was so high" (Observations; Ward C.1).* In contrast, she did keep a paper task list when working on a cardiology ward. This was possibly because

there was a higher proportion of patients staying for longer on this ward compared to the elective surgical ward and working practices varied. It was noted during the researcher's observations that the electronic task list contained tasks *"that were outdated e.g., a one for 20th Feb: 'check INR' although this was a month* ago" because the user had not 'signed off' tasks that had been completed, on the system*" (Observations; Ward D.2).* This emphasises the importance of maintaining the task list, especially when patients have been in hospital for a significant amount of time.

8.4   Chapter Summary

This chapter describes the various benefits and challenges experienced by users and the organisation's system development team when customising specific features of the system. These included: (1) customisation of the screen layout, which made it easier to view certain key pieces of information to improve patient safety. However, this sometimes came at the expense of making other information less visible and users were not always aware of how to customise their 'Medication List' view; (2) the inclusion of insulin ePrescribing and electronic recording of blood glucose results, which potentially contributed to safer and more efficient insulin prescribing. However, it also possibly contributed to clinical decisions being made in the absence of information that was not available on the system such as whether the patient was fasting; (3) the pharmacy task list allowed users to prioritise their workload and work more efficiently. However, some users highlighted shortcomings of this tool and were concerned that it lacked the sensitivity to detect all high-risk patients.

The system development team also introduced a range of CDS functionality into the system, incorporating a combination of approaches such as interruptive alerts and more passive methods (*e.g.,* the use of colour coding, order sentences, order sets and favourite lists, or mandatory fields). The following chapter outlines the benefits and challenges associated with using this CDS functionality.

Chapter 9

The benefits and challenges of interruptive and passive Clinical Decision Support approaches

The previous chapter provided an overview of how a commercial ePrescribing system had been internally customised by both users and the hospital's system development team after implementation. It focussed on the customisations made in certain three key areas: (1) medication and patient lists, (2) insulin ePrescribing functionality, and a (3) pharmacy task list. The system development team also incorporated a range of CDS functionality, including both interruptive (*e.g.,* alerts) and passive approaches (*e.g.,* order sentences and visual aids such as colour) that helped guide users through the medication use process. This chapter will explore the use of interruptive and passive CDS approaches and describe users' perspectives on the benefits and challenges of using these types of functionality based on data from the main study.

9.1   Interruptive Clinical Decision Support

9.1.1   Clinical Reminder

CDS alerts were used to support prescribers when writing a prescription for a patient. One doctor described how some alerts, such as the warfarin review alert, were particularly *"useful (…) if you don't know the patient"* as *"it pops up and you're like they're on warfarin" (P13; Doctor).* Another junior doctor also appreciated how the alerts reminded him to review a patient or medication, particularly if he was *"having a really busy day and you've got to prescribe loads of stuff and then you go' actually I'd forgotten about that'" (P15; Doctor).* One doctor also suggested developing an electronic task list or 'jobs list' for doctors, which *"deliver alerts all together" (P11; Doctor)* that they needed to follow up on, such as review a patient's blood glucose level or antibiotics. This could potentially be used instead of or alongside interruptive alerts so that even if alerts were overridden there would be a permanent place on the system that users could visit and visually see a list of tasks that still needed to be performed.

Users also commented on the potentially beneficial role of CDS for 'boardered patients' (patients with a specialist problem, who due to insufficient beds on the specialist ward were

staying on an alternative ward, *e.g.,* a renal patient staying on a general medical ward) as they potentially helped guide decision making for patients with co-morbidities that extended beyond their specialism. Renal patients were often under the care of various clinical teams, and one renal doctor suggested "*having an alert for people [clinicians] who come to our ward to prescribe for our [renal] patients just to remind them that actually this is a kidney, this is a dialysis patient*" *(P26; Doctor).* Therefore, the CDS could highlight important issues that non-renal-specialist care providers may not be familiar with, such as dosing requirements or blood monitoring.

> "*We have a lot of outliers, vascular teams and things like that and I just wonder whether it [the special prescribing needs of renal patients] gets thought about so much.*" *(P26; Doctor)*

For doctors who specialised in renal medicine an Acute Kidney Injury (AKI) alert was considered as not "*particularly helpful*" (P7; Doctor). In this doctor's view such alerts were superfluous as the user "*already knew the patient had an AKI and you were already trying to manage it*" (P7; Doctor). She also described how the alert had not triggered for certain patients in the past, such as those who had a "*really bad CKD [chronic kidney disease] or someone who was having [a] massive GI [gastrointestinal] bleed*" (P7; Doctor). The system development team decided to subsequently switch this alert off on the renal ward.

Interruptive alerts also reminded doctors that they needed to review certain medications. One doctor "*like[d] the way*" the system had in-built alerts that reminded her of "*medication [stop dates] and keeps on reminding you of medication, if you don't review it*" *(P11; Doctor).* However, a pharmacist suggested that users ought to be required to enter a stop date for medications that normally have a short course length *e.g.,* electrolyte replacement therapy, as prescribers "*shouldn't be able to prescribe them [phosphate or potassium supplements] without a stop date*" *(P21; Pharmacist).* This was because there was the risk that if a stop date was not added, the prescription could continue for longer than intended. As a result "*you see people on Sando K [an oral potassium supplement] for two weeks*" *(P21; Pharmacist),* which could result in hyperkalaemia (a higher than normal potassium level) from overtreatment. A doctor agreed, and went as far as suggesting that she "*would quite like not to be able to prescribe things like Sando K (a potassium supplement) without there being a stop date or have[ing] to specify how many days*" *(P24; Doctor),* thus raising the

question of whether the entry of certain information should be a mandatory requirement in placing some orders.

Another doctor felt that the content of some medication review alerts could also be improved as they were *"a bit non-descript in that it just says: 'this is finished' (…) but again it doesn't differentiate between what's sort of significant" (P20; Doctor)*. A pharmacist also commented on how the content of the *"window that comes up with BNF advice" (P21; pharmacist)* was *"not really small enough or concise enough",* and sometimes presented "*a whole page [of information] there" (P21; Pharmacist)*. In his view, the important points such as *"prescribe daptomycin CK [creatinine kinase tests] before and once a week" (P21; Pharmacist)"* could be easily missed or ignored. Another pharmacist felt that warnings should move beyond simply stating that there was a problem and provide specific *"information of [on] why a pop up has come up when they've decided to prescribe that medicine" (P31; Pharmacist).*

9.1.2 Alert Timing

The time at which alerts were presented to users was also felt to be important, and in some cases was found to be inappropriate. For instance, one doctor commented on how an antibiotic review alert often seemed to appear when they were "*in the middle of doing something else and so (…) you usually just click out of them and try and get on with what you're doing" (P7; Doctor).* This may have implications for patients, as another doctor explained how he had received an alert about an "*antibiotic (…) that's passed its review date"* at the same time as receiving other non-critical alerts, and consequently had mistakenly just clicked through and "*disregarded it as a useless box" (P20; Doctor).* Users often became desensitised to multiple warnings, which were displayed at the same time. Indeed, one doctor described the medication review alerts as *"a big grey thing, with a thing on it saying (…) 'to review this' "* and she admitted just *"click[ing] it off" (P24; Doctor).* Instead this doctor suggested that the system development team should consider changing the colour of these alerts from grey to green or to another more appropriate colour so that they stood out.

> *"If they [system development team] maybe just changed what they [the alerts] looked like we'd be like oh 'what's this?' and look into it a bit more. Make it like green or something. But until something happens like the antibiotics [an incident involving antibiotics not been reviewed] then I'm really, really stressed about it so I'll look into*

everything until something bad happens and then, you get a bit complacent I think"
(P24; Doctor).

One doctor also felt that it would be *"helpful and less [of a] nuisance"* if alerts were delivered *"all together" (P11; Doctor)* for one patient so that they could work through them at their convenience. However, this doctor also acknowledged that interruptive alerts were useful in a handover situation, particularly *"if it's not your patient [then] the [system] tells you something is going on with that patient" (P11; Doctor).*

9.1.3 Drug-Drug Interaction and Contraindication Alerts

A further key role of CDS at the prescribing stage was to remind a prescriber about the consequences of ordering two interacting drugs together or drug contraindications. Doctors welcomed alerts that provided them with clinical information that could inform their decision making. Doctors found an alert that warned them about the risk of overgrowth of *Clostridium difficile* in patients who were prescribed a proton pump inhibitor (PPI) with antibiotics particularly useful because it usually prompted them to *"suspend their [patient's] PPI or switch to ranitidine" (P20; Doctor)*. However, another doctor had witnessed a prescriber "*suspend a PPI [proton pump inhibitor] when they're [the patient was] only getting two doses of antibiotics so it didn't really need suspending, [but] because that warning comes up, then they did that" (P12; Doctor).* In this particular case, the patient was then prescribed ranitidine as an alternative to the PPI but "*would have been better staying on the PPI"* (*P12; Doctor)* as they had a stomach ulcer. One doctor suggested that certain information, which is currently available within the system, needed to be incorporated into the algorithms behind the CDS functionality. For instance a PPI/antibiotic warning would only be generated "*if the stop date [of the antibiotic] is more than however many days (...) and ignore it if it's only [a short course]" (P12; Doctor).*

The ePrescribing system had the capability to warn users about all drug-drug interactions, however, the system development team had chosen not to switch on this functionality with the exception of a few drug-drug combinations, which were "*a real issue" (P32; Pharmacist).* During testing, the system development team had found that many of the alerts that had been generated by the system were for medication combinations that were often "*used therapeutically in this organisation" (P32; Pharmacist).* One doctor valued this absence of drug-drug interaction alerts because the system: *"doesn't ever stop you, which is great when you're in a hurry and you know what you're doing"* (*P12; Doctor).* However, he did

acknowledge that some alerts may be useful for "*FY1s, [foundation year 1] FY2s [foundation year 2] or even some of the stranger [less common] ones [interactions]" (P12; Doctor)* where users may lack the knowledge to identify potential issues.

Although the system development team had intended to improve user satisfaction by limiting the volume of alerts presented, a lack of drug-drug interaction CDS in contrast also had been associated with some specific problems. Firstly, one doctor thought that it was *"a bit useless having a computerised system that is not being utilised to do things like that [interaction checks], to link to the BNF [British National Formulary] to have these things (…)* [it was] *"a bit of a loss that they're [the organisation] not using the system a bit better in terms of safety" (P26; Doctor)* to prevent errors. One junior doctor thought that the system *"shouldn't allow you to discharge a patient from hospital on two drugs that are, you know, contraindicated*" (*P15, Doctor)*. Another doctor, who had previously worked at a different organisation where drug-drug interaction alerts had been used more extensively, also commented on how there was "*nothing stopping you prescribing aspirin, clopidogrel, warfarin, tinzaparin (all drugs with antiplatelet/ anticoagulant properties) every combination you want" (P12; Doctor),* which could have serious clinical consequences for the patient *i.e.,* bleeding. Instead, another doctor posed that *"if a drug does interact (…) it would be good to have a box, a small box come up with a short, succinct reason why" (P25; Doctor)* for the prescriber to consider. In contrast, one newly qualified junior doctor actually felt that drug-drug interaction alerts were not necessary in the clinical area (cardiology) where he worked, as the drugs "*work in quite good harmony" (P18; Doctor).* Even if a patient was prescribed a standardised group of medicines for the treatment of myocardial infarction (MI), for example, it is dangerous to assume that these drugs would not interact with any of the patient's pre-existing medications or would be contraindicated based on any of the patient's pre-existing conditions or changing pharmacokinetic and pharmacodynamic parameters.

Furthermore, it was possible for users to assume that certain drug-drug interaction checks were taking place when in fact, they were not. One pharmacist commented on how "*people think it's more clever than it is" (P31, Pharmacist)* and could contribute to additional work for the prescriber. During observations the researcher noted how:

> "*A prescription for Ticagrelor (an antiplatelet) was generated by a junior doctor, an alert appeared, which stated that 'no drug interaction checks were being performed for this drug', the user then mentioned that she assumed checks were being*

performed for all other drugs. However, although the system was performing background checks, alerts were currently switched off and therefore would not have been presented, even if a potential drug-interaction did exist" (Observations; W24.4, Cardiology Ward).

Realising that the system did not perform all drug-drug interaction checks, a junior doctor commented on how he had to manually search for information about drug interactions that took time and how it was likely to be more efficient for the computer to do.

"It's actually quite difficult if you prescribe something to go and look up every interaction in the back of the BNF, but for a computer to do it, it's really easy because it just cross-references it doesn't it, with other drug names" (P15, Doctor)

The system did however utilise drug- allergy warnings that were generated if a medication or substance was prescribed that a patient had a documented allergy to, or was at a high risk of causing a cross-sensitivity reaction. For example "*if you say 'someone is allergic to tramadol' and you prescribe codeine it still goes 'ding"' (P15; Doctor),* which allowed the prescriber to use their "*clinical judgement" (P15; Doctor)* and decide how they were going to manage that problem.

9.1.4 Alerts generated at administration stage

Interruptive alerts were also used at the administration stage. One senior nurse liked a *"reminder"* alert generated by the system, which prompted him to check whether the controlled drug that he was about to administer was the correct preparation (*i.e.,* modified release or immediate release) *(P4; Nurse)*. He felt that it was probably beneficial for junior staff nurses "*because it makes them question what they're doing so they might have to ask somebody else" (P4; Nurse).* One nurse also valued how the system *"alerts you straight away (…) if you, click on to go and give them their paracetamol, [too early] not realising that it's a few minutes out" (P3; Nurse).* In contrast, another nurse described her frustration with this alert, explaining how the paracetamol alert prevented her from signing the dose off 'as given' until the minimum time dosing interval had been reached (*i.e.,* the previous dose of paracetamol must have been administered at least 4-hours ago). She therefore needed to remember to return to the patient at a later point and sometimes found them "*fast asleep" (P10; Nurse).* Although this nurse admitted that she could "*understand why" (P10; Nurse)* such safeguards existed in the system, the researcher observed instances where nurses

worked around this alert. For example, one nurse was observed *"leaving medication pots containing paracetamol doses for patients who were not due their dose for another 5 or 10 minutes, despite the presence of a CDS alert, so that they did not have to return to that patient" (Observations; Ward A.3).* The use of this workaround posed the question about whether refinements were needed, such as tailoring alerts to specific clinical areas or patients.

9.2   Passive Clinical Decision Support

Passive CDS approaches were also used in the system and included types of functionality such as the pharmacy task list (discussed in chapter 8). Further examples that were discussed include the use of mandatory fields and colour to direct users towards certain pieces of information on the system and the use of order sentences, order sets and favourite lists, which will be covered in more detail.

9.2.1   Mandatory fields and Colour

An alternative approach to using a hard stop alert (*i.e.,* an alert that would be generated if a field was not completed) was using one colour to highlight the mandatory fields. This was usually a different colour to the non-mandatory fields and had already been used for certain orders on the system. For example, one doctor thought the *"yellow boxes are [were] good because you know you have to fill those in before you can move on or order anything" (P24; Doctor).* One pharmacist recalled how *"when you are trying to prescribe some high risk drugs like cytotoxics it also has certain layers there in colour" (P21; Pharmacist)* that the prescriber had to fill in.

Colour was effective at supporting clinicians when they were reviewing a patient's blood test results as *"it highlights the abnormal results" (P12; Doctor).* For example, if a blood result *"was really abnormal, it goes red"* (P7; Doctor), which meant the user is likely to *"look at it more"* (P7; Doctor). However, a large proportion of patients with abnormal renal function might *"have trends of red" (P7; Doctor),* and so a more important piece of information for renal clinicians was the change in the patient's renal function from their baseline. One user questioned how the system could best illustrate a change in trend so as to help clinicians recognise *"how far up its gone or down" (P7; Doctor).*

Users also used colour to familiarise themselves with certain pieces of information quickly on the 'Drug Chart' and 'Drug Summary'.

> *"I guess the colour is used on the drug summary you get used to what you're looking for" (P8; Doctor).*

For instance, *"reds mean that it wasn't given to the patient, just on the administration [drug chart]" (P11; Doctor)* and would therefore draw the user's attention towards checking that. Another nurse valued the use of colour as it helped her identify the different statuses of medications *e.g.,* red for STAT (immediate) and green for PRN (when required) doses.

> *"I like that we have red, say for stat doses, (…) green that it's 'as required' [doses] that's quite good" (P9; Nurse).*

A pharmacist commented on how the colours helped her identify *"straight away" (P27; Pharmacist)* what medications were active or discontinued.

> *"It's blue if it's active, grey if it's recently been discontinued and then the PRN's are green. So I can see straight away because of the different colours, I can see straight away what is an active drug and it filters out all the stuff that I don't necessarily need to see" (P27; Pharmacist)*

One nurse suggested that it might be beneficial to display different routes of administration in different colours *"because we all would normally think paracetamol: oral, predominantly we're giving that oral. Then you might think IV but there are occasions when it's prescribed as PR [rectally] and people may not look at that (…) anything that helps you to sort of look and recognise [would help]" (P9; Nurse).* However, she acknowledged that there may be difficulties with this approach particularly if the "*preparation is [prescribed] either/or" (P9; Nurse).*

However, care is also needed to ensure consistency and that colours carry the same meaning throughout the system *e.g.,* red for a serious issue that required attention such as an out of range blood result or overdue dose of a medication. Furthermore overusing colour can confuse users, as one doctor admitted that there were already *"a lot of colours [in the system], I don't know what they [all] mean (…) I just thought it was colourful" (P11; Doctor).* It is important to use passive CDS to guide clinicians through processes in such a way that it

does not negatively impact on their workflow processes, whilst ensuring users are effectively warned about the serious issues in a timely manner.

9.2.2 The benefits and challenges experienced with using order sentences, order sets and favourite lists

9.2.2.1 Description of order sentences, order sets and favourite lists

An *order sentence* contains the drug name, strength, formulation and frequency, *e.g.,* lisinopril 10mg tablet ONCE daily; an *order set* contains a group of medicines (or blood test requests) that can be ordered together, *e.g.,* morphine, midazolam, hyoscine hydrobromide and cyclizine are the group of medicines contained in the 'care of the dying patient' order set (Figure 23). In some cases, order sets included medication and dosing options for those with renal insufficiency, thus making it *"much easier" (P7, Doctor)* to prescribe for these patients.
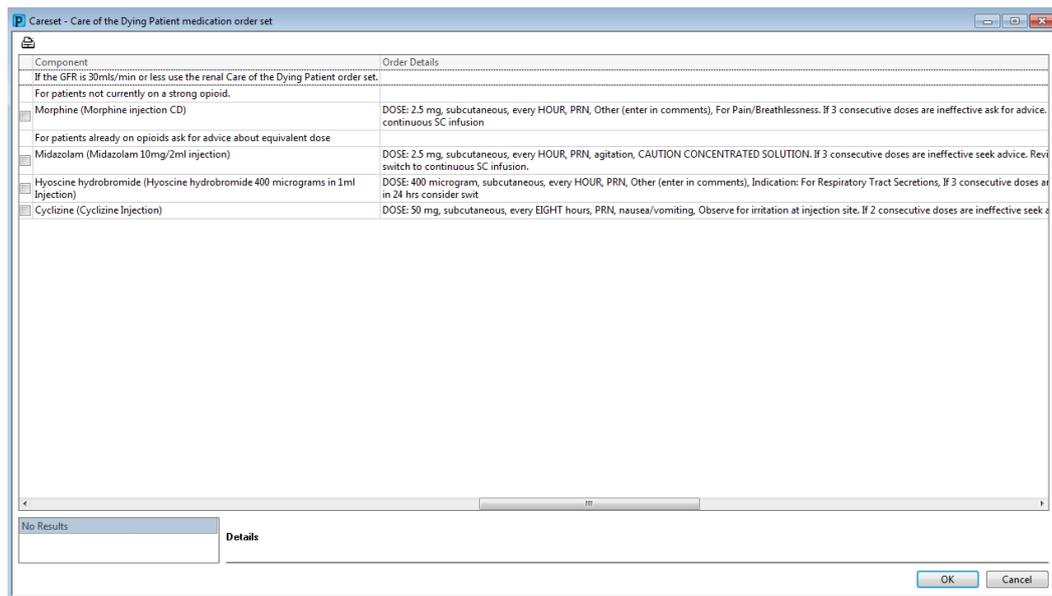
Figure 23: The 'care of the dying patient' order set. Users can choose to include or exclude individual medications by clicking on the box to the left of the drug name (first column on the left).

Favourite lists are groups of order sentences or clinical tests either selected from existing order sentences or made 'from scratch' by the user to improve accessibility. One junior doctor explained how a colleague had told him to "*make favourite lists kind of at the beginning of each job*" because "*it makes your life so much easier, which it does" (P16; Doctor).* Another doctor created a favourite list, which included a customised order sentence

for "*Oramorph (morphine sulphate solution), every hour" (P15; Doctor),* because he could not find this dosing option in the drug dictionary, and thus it was more efficient to select this order sentence from his favourite list than select each component of the prescription (*i.e.,* dose, frequency, route) every time he wanted to prescribe it.

> "*You can see like, things like, here for example, prescribe oramorph every hour and that's, you know so every time you do that you've got to go because it's never an option it's always four hourly, so you've got to go and find every hour so just having it there [in the favourite list]" (P15; Doctor).*

A rotational GP trainee felt that it was not worth creating a favourite list because he was "*only here for a few months" (P12; Doctor)* and some consultants "*even disagree among themselves" (P12; Doctor)*.

9.2.2.2   Development of order sets

The hospital system development team developed order sentences and order sets (drop down lists) to support users when prescribing. There were key factors that guided their development. Firstly, the system development team drew on the views and experiences of relevant clinicians to gauge what existing hospital treatment protocols "*would lend themselves to an order set" (P30; Pharmacist)*; they were considered "a *useful way of making sure that all of the bits of the protocol got put on the chart" (P30; Pharmacist).* Order sets were also developed "*in response to the fact that prescribing errors had happened" (P30; Pharmacist")* and to possibly prevent such errors happening in the future. For example, one pharmacist recalled how prescribing errors were more common in patients with peritoneal-dialysis related peritonitis (PD peritonitis). Despite the existence of a hospital protocol, prescribers were not familiar with the non-standard routes of administration for drugs such as tobramycin and vancomycin. The renal pharmacist explained how "*if you're an inexperienced SHO [core medical trainee] and it's in the middle of the night it's kind of difficult to get it right" (P30; Pharmacist).* The order set enabled the user to "*type in PD peritonitis or some combination of that [and] it brings up the pre-selected drugs, the pre-selected routes of administration and it's also built in a dose calculator as well, so in theory that's a really good way of preventing that error from happening again*" *(P30; Pharmacist).*

In addition to ordering a group of medicines, order sets could also be used to order a group of clinical examinations for a patient *e.g.,* all of the blood tests required for a patient with

suspected liver disease. However, some participants were concerned about the risk of over-reliance on order sets and how it could make the task of prescribing too simple and *"stops them [prescribers] thinking about it" (P30; Pharmacist).* For example, the renal transplant order set was described as useful for ensuring that clinicians prescribed all the relevant items, but perhaps not as helpful for individual patients who do not *"fit the protocol",* as doctors have become used to *"ticking [all] the boxes" (P30; Pharmacist).* However, one disadvantage of this that was highlighted by a senior pharmacist was that inappropriate medicines that were part of an order set, were sometimes prescribed because the doctor did not recognise (and failed to double check) items that the patient was already taking such as a COX-2 inhibitor, which could interact with items in the order set and contribute to an adverse drug event such as bleeding.

> *"They[the patient] might come in on a non-steroidal or a COX-2 and it's not such a common name, etodolac is the big one, [it] doesn't trigger in the doctor's heads and then they come along they prescribe the post-op order set, ibuprofen comes up and then they prescribe two NSAIDs (non-steroidal anti-inflammatory)" (P27; Pharmacist).*

Whilst another doctor noted how some of the more junior doctors *"might not recognise, they might not even consider that [dipyridamole] as [is] an anticoagulant or antiplatelet" (P12; Doctor)* and therefore fail to identify any potential issues when this is prescribed as part of an order set.

Finally, certain order sets that incorporated treatment protocols, *e.g.,* a post-myocardial infarction (MI) order-set had the potential to be useful as it could help prevent accidental omission of orders such as *"GTN sprays [which] often get forgotten" (P31, Pharmacist).* However, some consultants tended to be "*very prescriptive about which one of the second anti-platelet plus aspirin they want"* thus this order set was perceived as being too difficult to develop.

9.2.2.3   Decision support guidance within some order sets

Decision-making guidance was occasionally found within some order sets. These are highlighted in the red boxes given in the example below for Methicillin Resistant Staphylococcus Aureus (MRSA) eradication therapy (see Figure 24).

Figure 24: Order set for MRSA Standard Eradication Therapy, with integrated prescribing guidance highlighted in the red boxes

Indeed, one doctor suggested including *"things like [treatment] protocols"*, which would save users *"a couple of clicks to go in [to] another window and kind of search for it"* (*P12; Doctor*). He mentioned in particular the Venous Thromboembolism Prevention order set and how information like drug indication, length of treatment, and weight based doses should be visible at the point of prescribing. However, one of the system development team cautioned against the addition of more lines like this, explaining how it could potentially overload the user with too much information. Instead, he felt that it might be more prudent to have an order set that populates options based on the individual prescriber's previous selections, or an algorithm that the system can work through before suggesting whether a particular treatment is suitable for a patient.

> *"The community acquired pneumonia one, it was one of the first ones we built but its, it must have 30 lines in it there's a whole load of information to take in and you've got all of your prescriptions and have to work all the way through and I don't know how anyone would make sense of it, particularly when they are trying to do it quickly. So I think that [it] would be much better either broken down into smaller sets (…) then you open up more information when you click on it" (P32; Pharmacist).*

The use of algorithms that can provide patient-specific suggestions to the prescriber (*e.g.,* give directed dosage recommendations based on a patient's C - reactive protein level) require more complex functionality to be built into the order set. One pharmacist reflected on how*, "the build [for that function] looks pretty complicated" (P32; Pharmacist)* and therefore would take time to develop the expertise required to make such changes.

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9.2.2.4 Selection of Order Sentences and Order Sets

9.2.2.4.1 Challenges identifying order sentences and order sets and the clinical appropriateness of these features

In order to identify and then select a particular order sentence, the user needed to type in the first few letters of the particular medication and select the desired option from a drop down menu. One user found this *"really useful" (P7; Doctor)* as the drop down menu contained "*all the doses and readings that the BNF [British National Formulary] would suggest for that drug" (P7; Doctor*). By 'right-clicking' over the order sentence, prescribers could also quickly access additional information in the relevant section of the electronic BNF.

> *"You can right click on the prescription and see the BNF page for the drug and check your doses that way rather than having to go to the paper form every time you need to prescribe something" (P7; Doctor).*

This was particularly helpful for those who were newly qualified as they didn't need to look up each medication in the BNF, which saved them time. However, one newly employed junior doctor struggled to *"find the inhaler 'spiramax' on the system when she typed in the product's name" (Observations, Ward B.2).* This was because *"the default setting was set to 'starts with', which may initially restrict the search" (Observations, WB.2)* and the medication's full name was 'DuoResp Spiramax'. In this particular case, the junior doctor asked her clinical mentor why she could not find this particular order, who then explained that *"she may need to change the search terms from 'starts with' to 'contains' to bring up more options" (Observations, WB.2).*

One doctor also admitted that *"calcium supplements are [were] really difficult to prescribe"* (*P13; Doctor),* as the *"prescription only says the ingredients and not what the actual, what the shortened [brand] name is" (P13; Doctor).* This was echoed by a senior pharmacist who recalled how calcium preparations were a *"common source of error for everyone" (P6; Pharmacist).* For example, Adcal D3 Chewable Tablets contain the two active ingredients Calcium carbonate (1500 mg) and vitamin D3 (400 I.U.). This doctor admitted having to *"Google what the exact ingredients are [were] and then try and find it [in the system]" (P13; Doctor).*

A further problem was that paediatric doses were sometimes listed alongside adult doses *e.g.,* for an anti-emetic (cyclizine). One pharmacist found that certain doctors selected these paediatric doses in error and started adult patients on a sub-therapeutic dose of "*25mg three times a day" (P21; Pharmacist).* The hospital system development team also identified occasions where prescribers could not find certain order sentences that existed in the drug dictionary and thus resorted to *"always using [the miscellaneous prescribing option] because they are misspelling it [the drug name]" (P32; Pharmacist).* To overcome this issue, the system development team created an order set and assigned common miss-spellings of the drug's name to the correct treatment so that, even if the prescriber typed in the wrong spelling, the correct order sentence would be presented as an option for them to select, thus increasing the sensitivity of the drug dictionary.

> *"We can put in misspellings into the system (…) we make a [order] set with a miss-spelled nickname, which then guides them to that. So they're like little system you know exploitations that we've kind of came up with (P32; Pharmacist).*

It was also sometimes difficult for users to remember the 'key trigger words' to find particular order sets on the system. One user resorted to typing in *"a variety of different words" (P24, Doctor)* and then seeing what came up. A renal doctor explained how she *"couldn't remember the key word" (P26; Doctor)* that brought up the 'care of the dying patient' order set and felt that the key trigger word *"dying"* was a *"bit blunt"* for this order set. The researcher reflected on whether there could be a user-design mismatch, with different users referring to the 'care of the dying patient' order set in different ways, such as 'end of life', '*LCP [Liverpool Care Pathway]*', 'supportive treatment' and 'palliative care' during their interviews.

Issues were also identified when selecting the medication for a prescription, which was related to whether the medications were listed generically or by a brand name. In some cases a specific medication is better known by its brand name, however the system tends to list medications according to the generic name. This was, according to one pharmacist *"good"* because it *"encourage[d] generic prescribing"* however a nurse also felt that it was not always as easy to distinguish between *"different preparations of drugs" (P2; Nurse)* for example, diltiazem that is available in several different modified release preparations. Indeed, she attributed this to one of the causes of an error, where the patient should have been given a "*sustained or modified release and they [the nurse] were [was] just giving an*

ordinary preparation" (P2; Nurse). This poses the question about whether it should be possible to see the brand name alongside or by hovering over the generic name for certain medications.

Finally, some order sentences were also found to be not clinically appropriate. For example, the order sentence for 'phosphate binder' preparations (*e.g.,* calcium acetate) had originally been set up to be administered 'THREE times daily', which corresponded to doses at 7am, 12pm and 22pm. According to one of the nurses, the 22pm dose was "*completely useless, because it has [had] to be [taken] with food" (P1; Nurse).* The order sentence was subsequently customised by the system development team and the times now "*automatically default[ed] to those times [mealtimes 7am, 12pm and 6pm]" (P30; Pharmacist).*

9.2.2.4.2   A lack of structured order sentences for titrating doses of a medication

9.2.2.4.2.1   Titrating doses of a medication

There was a lack of structured order sentences for certain medication regimes, such as "*reducing courses of steroids or reducing courses of anything" (P30; Pharmacist)*, or non-standard doses, which made it difficult for users to select and prescribe these on the system. Instead some prescribers created individual orders, which would be issued one after another, with different start and end dates for the same medicine. For example, one doctor prescribed a non-standard dose of folic acid "*once a day on a Tuesday and once a day on a Wednesday"* (rather than selecting a twice a week option) *(P23; Pharmacist).* Another user described how she needed to "*figure out the dates, make sure you've done it [prescribed it] for seven days, and then write instructions next to each one so they [the patient] know to kind of step it down" (P16; Doctor).* However, this meant that there were potentially "*six or eight separate entries" (P16; Doctor)* for one medication, and sometimes the titrating course was "*not clear to the dispensary" (P21; Pharmacist)* or even contradictory. For example, a user could prescribe "*20 milligrams a day for five days and then in a special instruction field put "reduce by five milligrams every five days until you're at zero" or whatever" (P30; Pharmacist).* Titrating courses were also problematic at the discharge stage. For instance, if the prescriber had prescribed multiple orders for the same medication, but with different dates (*e.g.,* prednisolone 40mg from the 1st-7th May, prednisolone 35mg from the 8th-14th May etc.) and these were 'converted' from the hospital system to the discharge system, the dates did not

transfer over and thus the doses would appear without any instructions about how long they should be taken for. As a result, this pharmacist described how they would have to add a comment into the special comments field in order to make the prescribers intention clear for the pharmacy dispenser.

> *"It's for discharge that it's the problem. And some of them will prescribe I don't know 20 milligrams for five days, 15 milligrams for five days, 10 milligrams for five days but when that appears on the discharge prescription the dates don't pull across so it's not clear to whoever was dispensing it, and also they don't appear in order on the list either, either increasing the order or decreasing the order it seems to be quite random so you have to go in and modify it to put 20 milligrams daily for five days from whenever and manually put all the dates in so the dispenser can then type all that onto the label." (P30; Pharmacist).*

However, users suggested that it should be possible for the user to specify the starting dose, finishing dose, and the intervals *e.g.,* every five days, for the system to then automatically populate a titrating course. In addition, a senior pharmacist felt that the titrating course could also be easily misinterpreted by the patient, who sometimes did not know whether they needed to *"increase [the] dose, or (…) decrease [the] dose, or take them all together" (P23; Pharmacist).* Furthermore, if the *"consultant said actually we'll stay on the higher course for a little bit longer" (P8; Doctor),* this meant that the dates of subsequent doses could be *"out of sync"* and would need readjusting (or in this case re-prescribed), creating "*quite a lot of work" (P8; Doctor).*

9.2.2.4.2.2 Warfarin

Similarly, one nurse felt that *"the potential of making a mistake with warfarin is [was] huge" (P2; Senior Nurse).* It was not possible to order warfarin using a structured order sentence, so prescribers put directions in the free-text box, which she found difficult to interpret. For example, *"you have to read the instructions 26th 3mg; 27th 5mg; 28th … now there's nothing. So is that when we're checking the INR today? Or does that mean [something else]? (…)" (P2; Nurse).* Another nurse explained how doctors "*documented the INR rather than the warfarin prescription [in the free-text box] so it can sometimes be a little bit misleading" (P4; Nurse).* She recounted how '2' was entered in the free-text box for a patient whose INR was two, and

got easily misinterpreted by another nurse as *"2 milligrams of warfarin" (P4; Nurse)* to be given.

The *"bright yellow chart" (P26; Doctor)* at the end of the patient's bed had previously reminded one doctor that their patient was on warfarin and how she needed to check if their dose should be adjusted. However, since the implementation of the ePrescribing system, this visible prompt was no longer there. One doctor described how the lack of such a prompt contributed to the prescriber not reviewing one patient's INR and adjusting their dose over the weekend. However, the doctor did acknowledge that the ePrescribing system does have alerts, which flag up when the warfarin needs to be prescribed but this alert was only presented to the user on first entering the patient's record. One junior doctor suggested including a structured order sentence for the prescribing of warfarin, where the dose could be selected on different days via a drop down menu in order to make selecting doses easier and clearer.

> *"You could do right on Monday I want to, drop down menu, and I want to give 3[mg]*
> *and then at the same time you could order an INR for Wednesday. And even if it then*
> *just popped up at the end so you could sign for the INR that would work, that would*
> *work really well actually" (P15; Doctor).*

There were also challenges related to documenting warfarin on the system, as users were expected to record similar information "*in three separate places*" "*(1) a 'warfarin review form' [on the system], (2) a handwritten entry in the paper notes, and (3) on the system's 'documented medication history tab'* "(Observations; WB.1). The requirement to document the same information in three separate places in order to adhere to the hospital's policy, was noted to have increased the pharmacists' workload. One pharmacist was observed *"add[ing] the word 'warfarin' into the documented history but [with] no other details" (…) to avoid having to duplicate all of the same information that they had already entered into the warfarin review form" (Observations; WB.1).* This information included (a) the warfarin dose, (b) how long the patient was likely to be on warfarin for (*e.g.,* lifelong), and (c) what the patient's target INR range was. Another pharmacist was also not sure "*what value [documenting warfarin on the warfarin form] adds" (P27; Pharmacist),* as she felt that all that information was already there on the documented medication history tab. This also meant that if another user, at a later date, was only to check the 'documented medication history' tab, they would miss important information that was documented on the warfarin form.

9.2.2.4.3   Selecting the medication, frequency route and dose for a medication order

A senior pharmacist found that when prescribers were adding the frequency of a medication into an order sentence, they would *"type in the first letter [of the desired frequency]" (P30; Pharmacist)*, for example, 'o' for once daily (latin abbreviation 'od'), which would generate a list of possible frequency suggestions beginning with that letter (*e.g.,* ONCE). However, under the system's rules, the prescriber should type in *"'D' for day"* in order to generate a once daily prescription and so doctors *"often make the mistake of thinking it's O for once daily and the O for once is just the STAT [immediate once only dose] dose so you sometimes get something prescribed as a stat dose where they're intending it to be daily" (P30; Pharmacist).* According to one doctor extra care was also needed when prescribing a dose that was only due to be given once daily just after a drug administration round because the dose would automatically default to be given the following day, *"even though you wanted it [given today]" (P24; Doctor).* For instance, if a patient was due 'bisoporol' each morning at 8am, if the prescriber did not order this until 8.05am, an order would not be generated until the following day, and so the patient could miss today's dose unnecessarily. To get around this, the doctor would have to *"go back and do a stat [immediate once only] dose" (P24; Doctor).*

It was also sometimes necessary to prescribe a medication by more than one route according to the patient's clinical condition. For example, cyclizine (an antiemetic) was often ordered both orally and intravenously (IV) to allow the nurse to administer IV, if oral was not possible. However, one doctor explained how *"if you put one on oral and an IV there's a danger of them getting it twice if you don't suspend one" (P20; Doctor)* because the system allows duplicate orders of the same medication, without resulting in an alert or other CDS intervention. Similarly, for certain medications *e.g.,* tramadol (an opioid analgesic) it may be suitable to prescribe them both regularly *e.g.,* 50mg four times a day and 'when required', so that if the patient was in more severe pain the nurse would be able to increase a single dose from 50mg to 100mg. However, the system did not always provide such prescribing flexibility as one doctor described *"you can't select multiple [frequency options] you have to click tramadol PRN (when required) (…) and then click again and prescribe it regularly" (P12; Doctor).* Therefore, the doctor would order tramadol *"50[mg] 4 times a day" (P12; Doctor)* regularly and then place a PRN order; the default order sentence for the PRN option was *"50 [mg] every four hours PRN" (P12; Doctor),* which increased the risk that the patient might get too much if both order sentences were selected together.

One particularly troublesome order sentence that was associated with prescribing errors and mis-selection of the dose was tinzaparin. Nurses encountered difficulties when administering the dose of the anti-thrombotic medication to a surgical patient (4,500 units), as the pre-filled syringe that contained the dose (3,500 units) would have sometimes been mistakenly selected and prescribed on the system. One junior doctor suggested that this error may have happened because:

> *"Sometimes the anaesthetists or the surgeons downstairs prescribe it [tinzaparin] and because they're not familiar with it [the system], they prescribe 3,500 units and that's in a 0.35 pre filled syringe. And then I've seen a couple of times where that's come up to the ward and someone's tried to amend it and they've gone discontinue, re-order, and just typed 4,500 units but still in the 0.35 ml syringe and that doesn't work. And then the nurses come to you and go this is impossible" (P15; Doctor).*

This also raises the question of whether including an indication alongside the order sentence for the specific doses of tinzaparin may help reduce such selection errors.

A second problem also emerged with tinzaparin because the prescribed doses were not automatically rounded on the system. This made it difficult for nurses to administer certain doses without contacting the prescriber. A nurse explained how some doses that the doctor worked out were *"ridiculous, it will work out as say 14,235 [units]" (P14; Nurse),* so then the nurse has to contact the doctor or the doctor would ask the nurse *"will we go up or go down, just go to whichever is the nearest you know if its nearer to 14,000 go to 14,000; if its nearer to 14,500 go to 14,500" (P14; Staff Nurse, General Medical Ward).* Furthermore, the quantity of the injection *i.e.,* the 'millilitres' of the syringe volume that contained the full dose (*e.g.,* 14,500 units) was not automatically calculated by the system, which made some nurses very wary of administering such doses. One nurse explained how she would always ask another nurse to 'second check' her calculations and observe the administration, even though this was not required under hospital policy.

> *"So, say a patient was to have 15,500 units, so you're going to have to use an 18,000 unit syringe and calculate so it will have tinzaparin 18,000 units, underneath it will have 15,500 units. You've got to be careful. (…) In my mind, you're not just giving a standard one [syringe] that's already been pre [pre-filled], you know you're giving*

something that you're having to calculate and it could be completely wrong. It doesn't ask for a double signature but I always do" (P14; Nurse).

9.2.2.5   Modification of Order Sentences and Order Sets

Some users described the difficulties they experienced when modifying orders (*e.g.,* increasing or decreasing the dose of a medication). For example, if the order sentence included a strength of the product *e.g.,* 'darbepoetin 40 microgram pre-filled syringe, inject 40 micrograms ONCE daily', the whole order would need to be cancelled because, even if the 40 microgram dose was changed, the 40 microgram pre-filled syringe would still appear on the prescription.

> *"The mistake they sometimes make in that instance is like for example if something is a particular syringe size like darbepoeitin for example if they're on 40 micrograms and they want to increase it to 60 micrograms if they've prescribed it as darbepoeitin 40 microgram pre-filled pen and the dose is 40 micrograms if they do cancel and reorder it's still darbepoeitin in a 40 microgram syringe and they've changed the dose to 60 and the nurses would know that they would get a 60 microgram syringe but the correct way to do that would be cancel discontinue and re-prescribe it from scratch" (P30; Pharmacist).*

The same issue occurred for tinzaparin, which was sometimes prescribed in error at one dose and then modified to another; however, the strength did not automatically update. This relied on *"the nurses on the orthopaedic ward [to] know that it's four and a half thousand that we want [for a surgical patient], so they'd know to look at it more closely and give four and a half thousand" (P12; Doctor).* One pharmacist did not feel that *"doctors generally appreciate[d] the subtlety of that difference" (P30; Pharmacist),* while to a pharmacist it was *"dead obvious because when you're going to supply it you need the right strength of syringe" (P30; Pharmacist).* It is possible that the system could be 'more intuitive' and link the dose and strength so as to guide the prescriber when ordering tinzaparin, thus ensuring that the correct syringe is selected and prescribed with the correct dose for the indication.

It was also a similar case for oral capsules *e.g.,* Ramipril 2.5mgs where the user would need to *"cancel, discontinue, and then add Ramipril with the new dose or you could do cancel and reorder and it would bring up the same prescription and then you could just change the 2.5 [mg] to a 5 [mg]" (P30; Pharmacist).* However, if the order sentence did not contain the

strength of the product e.g. 'ramipril capsules', the dose could be simply modified by the user as the pharmacist above described.

9.3   Chapter Summary

This chapter described how the hospital's system development team had utilised both interruptive and passive forms of CDS and the benefits and challenges associated with these approaches. Some interruptive methods *e.g.,* alerts at the prescribing and administration stages, were valued by users as they could potentially contribute to reductions in medication errors. However, the conservative approach that the Trust had taken with regards to using drug-drug interaction alerts resulted in some users actively requesting for more safeguards to improve patient safety. Passive approaches such as mandatory fields and colour also aided users when ordering or reviewing a patient's medications. Finally, this chapter discussed some of the specific benefits and challenges associated with order sentences, order sets and favourite lists. For instance the researcher described these functionalities and their usefulness *e.g.,* more efficient prescribing by being able to prescribe groups of medications or blood tests from pre-defined sets. However, the researcher also highlighted some limitations of the system, which made it difficult for users to generate an electronic order.

The following chapter is the final results chapter and discusses the different training approaches taken by the hospital Trust in order to educate users on how to use the system, including a discussion of their relative merits and drawbacks followed by an overview of the areas that users lacked knowledge of, potential reasons for this and implications.

Chapter 10

Part I: What training approaches were used to educate clinicians on the use of a commercial electronic prescribing system?

In the previous three results chapters, this thesis has explored (a) the key challenges facing users when using specific design features of the ePrescribing system and how these gave rise to workarounds; (b) the benefits and challenges of a customising a commercial ePrescribing system and (c) the benefits and challenges of interruptive and passive CDS approaches. A further key factor that affected users' experiences was training. Some users were unaware of the system's known pitfalls or how to customise the system to enhance their experience of using it. This chapter is divided into two parts: Part I discusses the different formal and informal training approaches taken by the hospital Trust to educate clinicians on the use of the system, and the relative merits and drawbacks of these. These data were generated as part of the main study. Part II describes the different training approaches used in four hospital Trusts across the country and some of the benefits and limitations of these based on findings from the follow-on study.

10.1   Training Approaches

10.1.1 Formal training approaches for foundation doctors

Users described a range of ways in which they were formally trained to use the system. The formal training itself comprised of both lectures and workshop sessions, where the users were expected to work through a set of tasks such as prescribing *"warfarin, doing insulin, how to reschedule, how to suspend, and do all of those steps"* (*P32; Pharmacist).* Some of these tasks included scenarios that were informed by internal error reports, describing some of the known challenges of the system: *"setting up your patient lists correctly, because we've had patient mis-selection (…) what is a start date and time because people get that wrong, how do you reschedule a medication (…), it's not easy to spot how to do that" (P33; System Development Team).* One doctor found these scenarios helpful, particularly the patient list customisations task because he needed *"to know whose patients and things and who to call, it's quite quick reference sort of thing and then just all the identifiers to make sure you've got the right person before you go on" (P17; Doctor).* The final components of induction training

involved shadowing the existing doctors on the ward and working through a training exercise where they were *"given a fake patient and then like a workbook to work through common things"* that they would do, which one doctor found helpful *"for the first couple of weeks when you were still kind of getting used to it [the system] and you could refer back to that book if you got stuck" (P16; Doctor).* The foundation year doctor training was mandatory and protected time was given to this training during their induction week, which one user thought was vital because *"otherwise we maybe wouldn't have done it" (P16; Doctor).*

A member of the system development team explained how foundation year doctors were given *"the basics"* such as *"this is how you go into the system, this is how you go into your patient, this is how you prescribe, this is how you review, this is how you reschedule [a medication]" (P33; System Development Team).* However, by focusing on the basic elements of the system, there was a risk that some users did not *"know about the hidden functions that would actually make your [their] life a lot easier" (P29; Doctor).* For example, one junior doctor, who was interviewed shortly after he had begun working for the Trust, was unaware that order sets for certain treatments existed*: "Do they exist? I don't know (…) I've never seen them" (P18; Doctor).* Instead, one member of the system development team commented on how the Trust expected more specific (informed) training to be provided by *"the junior doctors that are [were] rotating off that ward or the more senior people"* on the ward (P33; System Development Team). She felt that these staff were better placed to deliver *"that kind of level of training"* as they were more familiar with the particular order sets or "*different things that they [newly employed doctors] need to do" (P33; System Development Team)*.

The lectures were not felt to be particularly useful by some users, with one junior doctor describing them as *"pointless because no one was listening most the time" (P17; Doctor).* This may have been related to the environment in which the lectures were conducted in, with another doctor remarking how *"crowding 80 people into a really hot lecture theatre at four o'clock on a Friday afternoon to try and teach them how to use [the ePrescribing system] without any physical hands on [exercises], it's just not going to work" (P15; Doctor).* A specialist registrar doctor recalled being overwhelmed by the large volumes of information that she received as a junior doctor, and only remembered picking up small pieces of information from the lectures. The workshop sessions and shadowing, where users gained 'hands-on' experience of using the system were considered by one doctor to be *"much better" (P18; Doctor)* than lectures, and *"really the only way to learn" (P18; Doctor).* Another doctor described how they had *"learnt much more by just learning in action" (P25; Doctor).*

One doctor described diving *"in at the deep end and started using the real system" (P15; Doctor),* which he actually thought *"was much more beneficial" (P15; Doctor)* during his induction week. He was able to familiarise himself with the 'live' version of the system during the shadowing induction week, and customise it so that it was "all set up" after shadowing *(P15; Doctor);* this was in contrast to other users who were given access to the training system, in addition to the 'live' system during the shadowing week.

10.1.2 Formal training approaches for non-foundation doctors

The system training offered to non-foundation level doctors (*e.g.,* specialist trainer level, registrars or consultants) when they began working for the Trust was less comprehensive than that given to foundation-level doctors. Their training comprised of *"a one hour, an hour and a half in a lecture theatre and do a quick demo and then we [the trainers] signpost[ed] them to training videos" (P32; Pharmacist).* One doctor explained how this level of training *"was fine"* for her because she had used the system previously as a foundation level doctor and felt comfortable using it. She "*pick[ed] up a few new things" (P24; Doctor)* at the training but admitted that she "*would have really struggled (…) with what training they gave us" (P24; Doctor)* if she had not used the system before. She described how her colleague had come from a different hospital (with a different system) and felt less prepared: *"she was like 'I don't know how to use it, I've just been shown for like half an hour how to do it and I'm expected to prescribe things' " (P24; Doctor).* Another specialist training doctor described her experience as *"a baptism of fire" (P8; Doctor),* finding it *"quite difficult to start off",* and so resorted to *"hassled [hassling] other people how to actually use it"* (*P8; Doctor*).

One of the foundation level doctor commented on how they had *"to train some of the consultants"* on the system *(P18; Doctor).* This was also witnessed during the observations: *"a consultant came into the doctor's office, they asked one of the foundation level doctors if it was possible to see an echo on the system or where it was. The junior doctor replied that it was possible and directed the consultant to the bottom left hand corner of the computer screen where the tab 'echo' was" (Observations, WA.3).* One consultant also admitted how she had not *"learnt how to prescribe [miscellaneous drugs] properly"* because she did not "*use it [the system] often enough and regular enough to know the qwerks and tweaks" (P28; Doctor).* She relied on her junior staff to prescribe on the system, although admitted having to "*upskill" (P28; Doctor)* herself during the time of junior doctor strikes. The staff mix on some wards also affected training. For instance, a foundation level doctor on the elective

surgical ward highlighted how the day-to-day medical service on the ward was typically provided by more junior doctors rather than registrars or consultants, as those members of staff were often in surgery or clinics. Thus, this junior doctor remarked that there was no one who he could ask for help with using the system as he was *"the most experienced person on this floor with regards to [the ePrescribing system]" (P15; Doctor).*

One speciality registrar commented on how it would have been useful if there had been *"a separate session going into a computer lab" (P29; Doctor)* in addition to the lecture that she recieved. Another speciality training doctor felt that users were at risk of *"get into bad habits of how to prescribe things"* and not "*look[ing] at things properly" (P24; Doctor)* without more comprehensive training, and that refresher training or "*a drop-in thing where people kind of get talked through the new bits of it" (P24; Doctor)* would be helpful. A senior pharmacist questioned the safety of locum doctors using the system without adequate training and especially if they have not used the particular system before *"because they've had no prior experiences and they're just doing as they find, [and] its quite frustrating for us; it must be very frustrating for them as well" (P6; Pharmacist).*

Pharmacists did not receive any formal training on the system after starting at the Trust. Instead, they learnt informally from their peers with one senior pharmacist recalling how his training comprised of *"two informal sessions in a room, a crowded room, four of us round one computer"* with their clinical mentor (*P6; Pharmacist)*. No formal training was offered when pharmacists changed roles *e.g.,* from a pre-registration pharmacist (who did not clinically validate prescriptions) to a pharmacist (who did clinically validate prescriptions), which resulted in one pharmacist feeling that he was left to *"see how you go, figure it out yourself"* through *"trial and error" (P6; Pharmacist).* One pharmacist felt that pharmacy users' knowledge of the system was actually "*better compared to that of other clinical staff"* (P21; Pharmacist), and they were *"sort of seen as the experts of how to use the ePrescribing system" (P6; Pharmacist).* There also appeared to be open channels of communication between the pharmacy ward staff and the system development team about the system. For instance one pharmacist described how she occasionally sends an *"email off to the [system development team] team saying please can we have an order set"* in response to an identified problem *(P30; Pharmacist),* or when there have been issues with the system. Another pharmacist recalled how "*an email came out from the informatics team telling us about it, highlighting it to us because obviously that's a risk" (P27; Pharmacist).*

10.1.3 Informal training approaches

10.1.3.1 Peer Training and Support

Peer training and support occurred across all professions and all levels of staff. One doctor recalled how "*the outgoing FY1's [foundation year 1 doctors] talked us through things" (P13; Doctor),* with one explaining how they customised their medication list screen in a particular way and *"found this particularly useful and [I] set mine up like that" (P13; Doctor).* Another doctor was told by the existing junior doctor during her induction training week that she should customise his medication list*: "they showed me there and then, and I did it" (P16; Doctor).* However, this doctor was responsible for providing subsequent training to colleagues, and admitted giving the new users *"a quick tour of [the ePrescribing system] and like where the most important things are but (…) [didn't] change anyone's orders of [medication] lists or anything" (P16; Doctor).* A colleague of this doctor also recommended that she should *"make favourite lists kind of at the beginning of each job and it makes your life so much easier" (P16; Doctor).* Another doctor explained how nursing staff had helped her out with *"changing like start times of things, (…) knowing that you had to give a stat first dose so it's just all the little quirks that you get used to" (P13; Doctor).*

Ward based training was also considered useful as it was *"tailored to what you need to do, which differs on each ward" (P18; Doctor).* One consultant described how when the transplant order set bundle was implemented, *"we educated all the clinical fellows (…) their supervisor was involved, all the consultants knew, because it was in the minutes at our monthly meeting, and then [the pharmacist] did some work with the nurses as well" (P28; Doctor).* The ward took a similar approach to training when they *"introduced the different forms of tacrolimus so the long-acting and then the generic form that we use mostly, [the pharmacist] did education about it with the nurses" (P28; Doctor).*

However, the researcher observed differences in the amount and type of informal training provided to new users across the different wards: *"the training given to one newly qualified foundation year 1 doctor on the general medical ward was less hands on than what was given on the surgical ward" (Observations; WA.3).* There was also differences in the amount of informal training provided within the same clinical area. For example, the cardiology pharmacist had been asked to deliver training *"four times a year, once with the registrars and three times with the SHOs [senior house officers] (speciality training doctors) [on the*

*cardiothoracic ward] as they rotate[d] round (…) highlighting the qwerks [of the system] (…)
[and] how to put an allergy to beta-blockers" (P31; Pharmacist).* However, no such training
was in place for the cardiology ward because *"they haven't asked us [the pharmacy team] to
do it" (P31; Pharmacist)* and so *"normally it's a case of 'hello I'm the pharmacist this is the
first day of your rotation, these are the things I need you to change' and then you just slowly
train them that way" (P31; Pharmacist).*

Due to the informal nature of the training, it was also vulnerable to interruptions as observed
by the researcher: *"a current junior doctor who had been working in the organisation for one
year was training a newly qualified doctor how to prepare a discharge prescription during
their induction shadowing week. The newly qualified doctor, asked the existing doctor 'how
do you know what she [the patient] was on before?', the existing doctor was about to tell the
newly qualified doctor but got distracted by a query from a nurse about a patient, she
subsequently did not tell the new doctor how to use the system in order to find out what the
patient was taking pre-admission by looking on the 'documented medications medication
list'" (Observations; WB.2).*

Some healthcare professionals felt that they lacked sufficient knowledge to answer specific
questions from colleagues around the use of the prescribing system. One pharmacist for
instance commented on how "*quite often the doctors will ask us how to actually prescribe
something on the system" (P23; Pharmacist).* However, because she did not "*have access to
that [the prescriber's] screen" (P23; Pharmacist)* she did not feel that she could help. A staff
nurse had also experienced doctors asking them to give advice related to prescribing on the
system but the nurse admitted that *"we don't have experience with the prescribing
aspect,[so] we often tend to be of limited help with that" (P1; Nurse).* Consequently, one
pharmacist described how he had to *"teach yourself [himself] all of these functions that you
don't actually use it for, for prescribing functions"* in order to support the medical staff *(P6;
Pharmacist).*

One pharmacist described this informal training process as *"not good enough" (P21;
Pharmacist),* with another pharmacist noting how some doctors who *"learn off their
colleagues (…) are probably learning bad habits" (P30; Pharmacist).* One doctor admitted
learning through a process of *"trial and error" (P22: Doctor),* while another only discovered
that a medication course had ceased when the *"nurses [are] telling you it's not prescribed,
or then you realise it hasn't been actually given" (P24; Doctor).* This was due to the issues

related to how the start and stop dates of medications were displayed in the default 'Medication List' view, as discussed in section 7.1.1. One nurse also recalled how the trainer: *"let us navigate around [the system] (…) and let us make mistakes so we could learn from them, not on real patients obviously, which is quite good" (P9; Nurse).*

10.1.4 Ancillary Training Tools

The final training approach participants discussed was the role of ancillary training tools, including the hospital Intranet (as a training source) and a workbook training manual. These could be accessed by users at a time that was most convenient to them, including out of hours, so that the user could *"refer back to that book if you [they] got stuck" (P16; Doctor).* One user explained how she *"went to the library after work and spent an hour going through tutorials and bits and bobs" (P26; Doctor)*. However, one foundation level doctor described the training manual as: *"a massive booklet, which shows you how to do everything with[the ePrescribing system]",* and so he had only *"skimmed"* over it (*P15; Doctor).* A speciality training doctor felt that it *"would be handy if there was a quick guide with common ones [shortcuts e.g., order sets]"* available *(P12; Doctor)* and that this would be *"definitely very, very useful" (P12; Doctor)* if positioned next to the computer *i.e.,* attached to the computers-on-wheels*.* One doctor remarked how she did not feel that she was *"getting as much out of it [the system] (…) because I [she] just simply don't know all the functions" (P29; Doctor).*

10.2   Gaps in user's computer skills knowledge

Certain users also discussed their lack of computer skills and how this affected their performance. One staff nurse who had recently returned after a number of years away reflected on how different she found the change from paper prescribing to electronic prescribing. She found the system *"completely new"* and was not "*very computer literate*" and even found "*moving a mouse tricky".* She worried that she might *"break it [the system]" (P10; Nurse).* One pharmacist also remarked that although "*a lot of people that use computers know that a right click will give you options" (P30; Pharmacist),* she also recognised that some users might not. Performing this 'right' click was needed to create a discharge prescription, and so users must have an understanding of these rather basic computer functions.

10.3   Part I Chapter Summary

This chapter discusses users' experiences of the different informal and formal training approaches taken by this hospital Trust in order to train users on how to use the system, including practical, classroom based sessions, lectures, ancillary training tools and peer training strategies. The second part of this chapter examines how users were trained in four large hospital Trusts across England (the main study site and three other sites).

Part II: How are users trained to use electronic prescribing systems in other hospital Trusts?

Part II of this chapter provides an overview of the range of formal and informal training approaches that were used to train users of ePrescribing systems across four large hospital Trusts, one of which was the main study site described in part I. This included classroom-based approaches and lectures, in addition to super-users, ancillary training tools and e-learning. These findings were generated as part of the follow-on study.

10.4 Formal, Structured Training Approaches

All stakeholders described using an element of formal, structured training in order to educate prescribing staff on how to use the system when they first began working for their particular hospital Trust. These specific approaches varied between Trusts and depended on the role of the user. A trainer at one Trust for example described how she delivered a one hour lecture to junior doctors *"where we talk to them about the prescribing system and about errors that we see (…) Give them a brief overview, a demonstration of the system"* followed by *"a 2 hour session (…) in front of computers" (P33; Site A)*. She acknowledged how foundation level doctors were given *"loads of information"* during their induction training week, which was possibly *"quite overwhelming"* for them and reflected on how they may *"forget pretty much all of that [training]" (P33; Site A).* A member of the ePrescribing team from a different Trust explained how they provided *"a combination of classroom training and also some handbooks"* to prescribers *(P34; Site B).* Prescribers at a third Trust needed to *"complete and pass our [their] e-learning ePrescribing course, which is about how to use the system" (P35; Site C)* as part of their initial training.

10.4.1 Practical, Classroom Based Sessions

10.4.1.1 Training Domain

Three hospital Trusts used classroom based sessions, during which the user was given a short demonstration of how to use the system and then permitted to practice in a 'training domain' or *"safe playground environment" (P34; Site B)* that mirrored the live system. This allowed users to both familiarise themselves with the layout and functionality, and also gain some practical experience. At one Trust, this training domain was accessible to foundation level doctors *"at various times" (P34; Site B)* in their induction week*. Dummy patients and

patient scenarios were incorporated into the training domain so that users could gain 'real-life' experience of using the system. However, some members of the ePrescribing team acknowledged that the resources required to *"create dummy patients on the system" (P33; Site A)*, and develop and manage the other elements of the training, was *"absolutely huge" (P33; Site A).* One member of an ePrescribing tem also felt that it was difficult to ensure that the training domain reflected *"the live system as much as possible" (P36; Site D)* because *"recent developments in the live system"* may *"not necessarily [be] mirrored in the training domain immediately" (P36; Site D).* This could be *"frustrating for users"* as they would *"be taught one thing and then go onto the system"* and find that *"it's slightly different or significantly different" (P36; Site D).*

10.4.1.2   Clinical Scenarios

The members of the different ePrescribing teams often discussed using material that was based on 'real-life' scenarios during their training sessions so as to try and *"make it as real as possible" (P35; Site C).* Trainers tried to "*tailor the content and the examples to that area [specialism of user], for example, if it was paediatricians they [the trainers] will try and make sure that they are using examples when it comes to prescribing or ordering from paediatrics" (P36; Site D).* This involved *"tell[ing] them [users] how to prescribe certain drugs for a child of a certain age and weight" (P36; Site D).* Similarly, at another Trust, users were required to *"complete particular tasks and workflows from a clinical perspective",* which involved *"how to admit a patient and how to discharge a patient, (…) how you prepare their medicines, when you do your discharge prescribing around the time of discharge. So it's become a much more workflow orientated way rather than individual tasks" (P34; Site B).* According to this member of the ePrescribing team, taking this approach *"made a lot more sense to people" (P34; Site B)* with another reflecting on how the training should incorporate the *"interaction [of the ePrescribing system] with other clinical systems" (P35; Site C)* such as a separate specialist system for prescribing chemotherapy.

Another interviewee also commented on how they had *"tried to spend a bit more time [during training] on the more complicated prescribing [tasks], so things like anticoagulation, insulin and also the prescribing of fluid" (P34; Site B).* This decision was informed by the *"committee for safety of medicines [expert team] within the hospital" (P34; Site B)* that concentrated on areas of *"high risk"* and was also *"heavily influenced by feedback from previous classes" (P34; Site B).* They also cautioned users about some of the known

challenges or *"quirks of the system",* as the system had been developed in the US and so *"occasionally [with] terms" (P34; Site B)* that would be more common in that country, were included*.*

10.4.1.3   Trainer experience

At one Trust, the ePrescribing team had tried to match the trainer's clinical role *e.g.,* doctor to the clinical role of the user group being trained. For example, they would select a doctor to deliver *"a session for the doctors (…) [and] similarly if it was nurses we would get one of our nurses on" (P34; Site B).* However, another site acknowledged how it was not always possible to get clinicians as trainers because they *"tend[ed] to be more expensive and you can't get clinicians from every background of the people you'd be training" (P36; Site D).* There were some benefits in using trainers from different backgrounds, as *"occasionally you get a doctor [who] might ask 'well, if I've done that, what will the nurses see?' so you need a trainer than can answer those sort of questions" (P34; Site B).*

10.4.1.4   Top-up Training

Additional training sessions were often provided to support users who were identified as having *"a real problem" (P35; Site C)* with a particular element of the system. Although *"extremely uncommon" (P36; Site D),* it was felt necessary for some of the more *"experienced staff" (P36; Site D)* who were less computer literate or for a user who had changed roles or acquired additional responsibilities (*e.g.,* a nurse who gained a prescribing qualification). In this case, one Trust provided the nurse with a *"specific prescribing session to basically go through all the same things that the doctor or a pharmacist would have got in terms of prescribing" (P36; Site D).* Top-up training may also be required after a system update, although one member of an ePrescribing team highlighted how doctors *"don't look at their Trust email account" (P34; Site B)* so it is difficult to make them aware of this requirement.

10.4.2 Assessment

The use of assessment as part of user training appeared to vary between Trusts, with one having no formal assessment but rather *"a number of (…) learning objectives that we need to achieve" (P36; Site D).* Other Trusts held a *"short assessment at the end of the classroom training" (P34; Site B)* to *"identify those people who have perhaps struggled with the training"* so that they could "*either keep them back a little bit longer on that day or otherwise bring*

them back on a another day for a bit more training" (P34; Site A). A different Trust that used e-learning for the majority of their training required the user to complete a mandatory assessment and *"get 90% in [order] to pass" (P35; Site C)* and start using the system. If an individual was identified as struggling, they would then be provided with one-to-one training to help support them.

10.4.3 e-Learning

One Trust trained all of their staff using an e-Learning based approach exclusively. The *"interactive" (P35; Site C)* training covered all aspects of how to use the system and was modelled around a *"watch and do"* approach that was considered mandatory for all users. According to this member of an ePrescribing team, this approach was a more efficient way of training large numbers of users *"because of the size of the Trust" (P35; Site C).* The training was comprehensive enough to cover the scope of tasks undertaken by a wide range of different users, whilst also been specific enough to ensure that users engaged with the training. The Trust had previously used three different sets of e-learning depending on the user's 'prescribing' or 'administration' roles, but this approach was unsatisfactory as nurse prescribers needed to both *"administer and prescribe, and some of the prescribing they don't do" (P35; Site C).* This particular interviewee was conscious that including unnecessary material in a training package ran the risk of such users becoming disengaged and *"lose[ing] them through the process" (P35; Site C).* To overcome this, the Trust moved towards using a modular training course consisting of *"about (…) 22 modules (…) covering all aspects of how to use the system from finding a patient, adding allergies, adding heights and weights,[to] adding your initial prescription and then modifying your prescription" (P35; Site C).* The individual user would then complete relevant modules that were tailored to their role, so a consultant would, for example, *"have to do modules 1-6, 8, 10 and 12" (P35; Site C).* They also created tailored training 'streams' for new roles based on the pre-existing modules and newly employed doctors received a 10 minute face-to-face session referred to as the *"safe prescribing part" (P35; Site C),* which was about ensuring that aspects *"not covered at all, that we need to highlight to them, other areas that they need to take care when they are prescribing"* were discussed *(P35; Site C).*

Another Trust planned to use e-learning as a form of 'pre-training' so that users could *"log in and do some basic things around you know, how to log in and how to orientate yourself with the screen that you might see and then we would probably do the classroom training*

next" (P34; Site B). Following the classroom-based session, this member of an ePrescribing team commented on how the e-learning could potentially be used again to reinforce or sum up the face-to-face training, or to help refresh users who were *"having any problems" (P34; Site B).* This member of an ePrescribing team recognised how further guidance may be needed *"particularly [at] weekends when there are fewer people around" (P34; Site B).* Another member of an ePrescribing team discussed the potential for e-learning to be used *"in the context of locums" (P36; Site D)* as it was an accessible and convenient approach to ensure that locum staff received a minimum level of training before they began using the system. One Trust actually required locum nurses to have completed the *"e-learning in advance" (P35; Site C)* before they could book a shift. It was not possible, however, to apply the same rules for locum doctors at this site because they were not booked via a central agency. Often locum doctors would *"turn up, [and] the [existing] doctor would go, 'here you go, here is my password, user name and everything for my systems- go ahead and work, take over" (P35; Site C).* To address this sharing of passwords and locums essentially working under another colleague's log in, the Trust took the decision that locum medical staff who were going to work for *"three nights or less" (P35; Site C)* were allowed to skip the formal e-learning and instead *"just do the quick assessment" (P35; Site C)* to ensure that they were *"doing things under their own log-ins and not someone else's" (P35; Site C).* It was hoped that by delivering mandatory training sessions to all other ward staff, they would be able to provide the locum with additional support if needed. However, it is worth noting that some ward staff at this Trust only received very basic or minimal training, and therefore were unlikely to be highly proficient at using the system.

10.4.4 Ancillary Training Tools

All sites provided ancillary training tools to users. At Site A, examples of these tools included 'how-to guides' which consisted of a *"one side of A4 on how to prescribe a STAT [once only, immediate] dose" (P33; Site A),* video demonstrations *"about prescribing, about administration, about blood ordering, those kind of things" (P33; Site A)* and *"little PDFs that you can print out or look up electronically [on the intranet]" (P33; Site A).* The foundation level doctors were also provided with a handbook as part of their induction training, which included *"top tips about customising your view" (P33; Site A)* and other tips about using the system. Importantly, users were able to access these tools electronically from anywhere in the hospital site. Another Trust physically printed and handed these documents to users, explaining how it was *"important for them to read" them (P35; Site C).*

The ancillary training tools at one Trust were *"all internally made" (P33; Site A)* and at another Trust had been developed based on *"feedback"* from *"members of staff" (P34; Site B)* who were not part of the informatics team. This was echoed by another member of an ePrescribing team who described designing their 'handy hints guides' around *"things that people have problems with that we know"* and *"incidents related to ePrescribing" (P35; Site C)*. Another Trust also provided 'tip-sheets', which were *"designed to support them [users] whilst they're out in clinical areas doing work" (P34; Site B)* and provide information about *"how you do x, y and z" (P34; Site B).* However, despite there being, as one member of an ePrescribing team described: *"a mountain of information available to them [users]" (P33; Site A),* it was not always clear how much users actually availed of it. As one interviewee commented *"if they [the users] have problems or questions they tend, I doubt that they go to the crib sheet as much as they ask colleagues or you know another prescriber to see if they can help" (P36; Site D).*

10.5   Informal Training Approaches

10.5.1 Ward Based Learning

Some Trusts tried to move away from the more traditional 'classroom' based approaches to ward based learning. For example, foundation level doctors at one Trust had spent time *"shadowing" (P33; Site A)* other doctors on the ward that they were going to start working on, during their induction week. Although the general training would be delivered by the Trust, it was felt that *"the nitty gritty day-to-day of what you do in that area that should be coming from those, the junior doctors that are rotating off that ward or the more senior people who are in that area" (P33; Site A).* In this way, the training delivered was more specific and tailored to the user and potentially more relevant with *"a F1 [foundation first year level doctor] will ask a F2 [foundation second year doctor] and suchlike whose got a bit more experience in the system" (P36; Site D).* Another Trust also used peer training and described how they had *"trained up two or three nursing members of staff for each ward"* who then go on to educate other ward staff during *"their local ward meetings" (P34; Site B).* A further advantage of using peer-training strategies is also that these 'trainers' were felt to be always available and could troubleshoot on demand.

Ward based super-users had also been used in some Trusts, either appointed on a formal or informal basis. Another Trust considered all of their pharmacy staff *"very good users" (P35;*

Site C) who could *"support the junior doctors"*; this approach appeared to have been *"push[ed] (…) as much as possible" (P35; Site C).* However, one member of an ePrescribing team reflected on how it was important to get the right individuals who were *"really enthusiastic" about (using the system) in the role of super-users*, rather than *"a team of people that didn't really know what the system was about, had been told they were going on 'this training session' and came along because they had nothing else to do" (P33; Site A). According to this member of an ePrescribing team,* this enthusiasm of the super-user affected the success of the roll out as *"it was really, really obvious when we went to those wards, (…) we [the super-users/ trainers know what we're doing and it was much smoother"* whereas on the wards with less-engaged super-users *"they went and hid in the linen cupboards, it was a nightmare!" (P33; Site A).* Another member of an ePrescribing team highlighted how it was often a challenge to make sure that super-users were *"available when you need them (…) and [how] getting the numbers that you actually need to support staff is [was] very difficult" (P36; Site D).* Another user echoed this and mentioned how "*everybody else in that department abdicates responsibility to them" (P34; Site B)* and the super-user could *"become swamped with stuff and they still have their own jobs to do" (P34; Site B).*

10.6   Chapter Summary

Part 1 of Chapter 10 discusses users' experiences of the different informal and formal training approaches taken by one hospital Trust in order to train users on how to use the system, based on the data from the main study. Part II of Chapter 10 provides an overview of the training approaches used to train users of ePrescribing systems across four large hospital Trusts (the main study site and three other sites) as part of the follow-on study. The members of the different ePrescribing teams discussed using a range of different methods such as formal classroom based sessions, interactive e-learning exercises and some informal strategies such as the use of super-users and peer-support. Indeed, a combination of different approaches has been used at some Trusts to potentially satisfy the learning styles of different users. It was also clear that regardless of the approach taken, the content should be tailored and informed by 'real life' practice or patient scenarios to engage the user. Certain challenging areas remain, such as how to effectively educate users about changes to the system over time and delivering training to locum staff in a robust and reliable way.

Chapter 11

Discussion and Conclusions

11.1 Introduction

An aim of this PhD programme of work was to explore the literature pertaining to the recent developments and persisting issues with ePrescribing and CDS systems and to provide a comprehensive overview of the unintended consequences of these systems across both adult and paediatric patients. These revealed a taxonomy of factors, which have contributed to errors during use of these systems e.g., the screen layout, default settings and inappropriate drug-dosage support. The researcher then conducted an empirical study to explore users' experiences of using a commercial ePrescribing system. This research used a qualitative approach, more specifically semi-structured interviews and observations, to generate a deeper understanding about how users used the system. This included the benefits and challenges associated with customising the system, actual practices and workarounds, areas in which the system could be further optimised to improve safety and usability, and the importance of user training. A further literature was then performed to complement emerging themes relating to how users are trained to use ePrescribing systems, which were generated as part of the qualitative study. Finally, this literature review and the results from the qualitative study led on to a follow on study, whereby the researcher conducted semi-structured interviews to examine how users were trained to use ePrescribing systems across four NHS Hospital Trusts. This revealed a range of approaches that were used to train users such as tailored training, lectures and e-learning.

 Human factors are hugely important and systems must be designed and optimised with user involvement and an in-depth understanding of how users interact with these systems in their usual practice. Several key findings are discussed in more detail later in the chapter, including:

- The difficulties users experienced when viewing and documenting information on the system and across disparate systems, and the need to reduce the number of screens that users must navigate through to find important information such as a patient's allergies or antibiotic stop date.

- The importance of end-user testing and involvement in all stages of the development and implementation of ePrescribing systems, in particular when designing symbols and icons to ensure that they have a transferable meaning.

- The issues that users described with the prescribing process, including differences between users' and developers' meaning of certain terminology, which resulted in confusion and delays when identifying order sets and medication errors.

- More patient specific information should be utilised within CDS algorithms and the role of indication-based prescribing, which can suggest appropriate doses and treatments.

- Unstructured orders such as titrating doses of steroids are error-prone and system developers should focus on how to create structured orders in ePrescribing systems.

- There is scope for the use of mandatory fields to encourage users to provide a course length for short-term medications and to expand the use of DDI alerts for high-risk drug combinations.

- The development of a pharmacy task list allowed users to prioritise their workload and identify high-risk patients. However, further refinements are needed, such as incorporation of additional patient specific information to help pharmacists judge the level of patient risk more accurately.

- Users discussed some of the benefits and challenges of different training approaches. Training that was tailored to the users' role was appreciated; however, due to resource limits this was not always possible.

- And finally, e-learning may offer a potential way of training large numbers of users in a consistent and standardised way, and further research should explore users' experiences of this approach.

11.2   Strengths and Weaknesses of the Programme of Research

This research provided detailed insights into the recent developments and persisting issues and unintended consequences of ePrescribing and CDS systems based on a series of three comprehensive literature reviews. A qualitative study was then conducted to explore users' experiences of using and being trained on a commercial ePrescribing system in a U.K. hospital Trust. A literature review and follow-on study then revealed the range of approaches used to train users on an ePrescribing system. However, there were a number of important limitations, which should be acknowledged. Firstly, the main research study took place

within one hospital Trust, which used a single ePrescribing system. The results are therefore unlikely to be generalisable to other hospital sites. However, some users had worked at different hospitals and used different systems prior to starting at the study site, often making direct comparisons between systems. A range of participants (*e.g.,* doctors, nurses, pharmacists and pharmacy technicians) were recruited across four different wards (*i.e.,* general medicine, general surgery, renal and cardiology) as part of this programme of work and it is possible that users may have experienced similar or different issues using the system in other specialities *e.g.,* paediatrics or neurology. However, some interviewees had rotated across these different wards and commented on their experiences. Data collection continued until thematic saturation was reached on these four wards.

Use of both semi-structured interviews and observations of different types of healthcare professionals allowed for data triangulation. A number of interviews (n=4) were also conducted with key stakeholders at the main study site and three further hospital Trusts to explore the training approaches used at these sites and the benefits and challenges of different approaches (the follow-on study). Although common themes did emerge from these interviews, the number of interviews conducted was small and only concentrated on a limited number of training approaches.

11.3 Reflexivity and the Role of the Researcher

The researcher had significant experience of working as part of a hospital pharmacy team and had also conducted several literature reviews exploring the use of ePrescribing. The experiences and knowledge acquired as part of this helped the researcher construct understanding and meaning from the data, which may have differed to a non-clinical researcher. However, it was important that the researcher was aware of their role in the co-construction of knowledge. To maintain validity and reliability, the researcher took steps to make their own thoughts and interpretations clear during the data collection and analysis stages. This helped to acknowledge and set aside her own biases and preconceptions.[178] For example during observations, the researcher annotated any of their own thoughts or reflections with 'OC' (Observer Comment), this could then be distinguished from actions or comments made by participants, which were annotated with 'SC' (Subjective Comment). This was useful when returning to the data during the analysis stage to give any background context to the field notes and allowed the researcher to honestly reflect on how their own thoughts may have influenced any interpretations made. During the charting stage of the

analysis, the researcher included a column where she documented any of her own emerging thoughts and ideas. This helped ensure that the analysis process was transparent and allowed the research team and stakeholders to evaluate how themes were formed. Furthermore, the researcher kept a research journal, documenting any thoughts, preconceptions and emerging ideas about the data, to enhance the credibility of the findings.[274] Importantly, the researcher also considered the intersubjective reflexivity between herself and the participants, i.e., *the mutual meanings emerging within the research relationship.[280]* Finlay described how a researcher's mutual understanding of a participant's experiences along with theory may be used to direct probing and further questions. In addition, Finlay noted how researchers who 'self-identify' with the participant may be better able to build rapport and be better, more engaged listeners during an interview.[280] This stems from a mutual understanding about a concept and thus the researcher and participant were, perhaps unconsciously, able to build a relationship. However, how the participant perceives the researcher (and vice versa) may also bring about challenges and could negatively influence the relationship. For example, if there was a perceived 'power imbalance' or anxiety if the researcher was identified as an external 'auditor'. Unconscious factors that contributed to the researcher-participant relationship were also noted by the researcher of this PhD. For instance, although the researcher never explicitly introduced herself as a pharmacist, she was introduced to the ward staff by a member of the hospital pharmacy team, in addition she wore an 'NHS Lanyard', which was a requirement as part of the Hospital's security arrangements. This may have given participants the impression that the researcher was also part of the pharmacy team or 'belonged' to the NHS in some capacity as opposed to an external researcher. If asked, the researcher did acknowledge their prior experience, although this information was often assumed. This was felt to be useful when interviewing ward staff because they were able to speak freely and use medical-jargon, allowing the participant to freely describe an experience, as if they were talking to a colleague, rather than have to 'translate' it into plain English. For example, one doctor discussed some of the issues with having dual ePrescribing and paper prescribing process in place for different medications. He used medical jargon, without the need to explain terminology, referring to the difficulties prescribing a "*a GKI infusion (…) because there's a chart and there's an [ePrescribing] thing at the minute so sometimes nurses just want one, sometimes they want both (P20; Doctor)."* He also indicated that he expected the researcher to understand the meaning behind their statement, for example when he made the point that it was *"probably [better] just [to] have everything on*

The strength of the researcher-participant relationship was also felt to have helped minimise the Hawthorne effect during observation sessions as the researcher noted how participants did not appear to change their behaviour based on how they would normally work. For instance, the researcher observed a nurse workaround an alert that warned her against administering a dose of paracetamol too early. The nurse proceeded to dispense the dose and hand it to the patient because the dose was due in 8 minutes time, even though this was technically too early *(Observations; WA.3).* The researcher reflected on the fact that the nurse had perhaps felt comfortable acting in this way because she was working within her clinical and professional judgement, which she possibly expected the researcher to understand.

The researcher was conscious of how her own experiences could contribute to data collection and analysis. She therefore took steps to declare any biases and document throughout the analysis how any interpretations were formed. However, the researcher also reflected on how her role positively contributed to the data collection process and allowed strengthening of the researcher-participant relationship and thus overall was considered to be a valuable component of this research.

11.4 Main Findings

11.4.1 Viewing and Documenting Information

11.4.1.1 Screen Display: Reducing the Use of Multiple Pages

One key issue with the ePrescribing system related to how medications were displayed and organised in the 'Medication List', which was a source of both error and frustration for users. In particular, the use of multiple screens, which fragmented the display of medication information, made it difficult for some users to interpret exactly what the patient was prescribed. Khajouei and Jasper's systematic review also highlighted how users had to scroll between several screens to see the whole medication record for a patient or rely on their

memory of orders, which is clearly error prone.[215] This programme of work also highlighted how the stop date of the medication was not always visible and possibly contributed to some doctors mistakenly thinking that the patient was still receiving the medication when in fact it had been stopped. The 'Medication List' should allow users to view the start and stop dates of all prescribed medications and the status of the medication *i.e.,* whether it is active, discontinued, suspended or documented, on one screen without the need to scroll. It should be clear to the user if the list has been curtailed in any way, thus prompting them to scroll or navigate to another screen to see this information. In terms of allergy information, users may also have found it helpful if the full medication name(s) was displayed when the cursor hovered over the allergy field, thus reducing the need to open a second screen.[127]

It was not always possible to view all (or a sufficient amount of) blood test results on one screen in order to interpret a trend. Displaying blood glucose results vertically and grouping them according to the time of the day may have made it easier for users to compare results taken at similar times of the day. Indeed, the Health and Social Care Information Centre issued guidance for displaying results in graphs and tables, and recommended that users should be able to adjust the system to display the graphs and tables according to their own preferences.[281]

11.4.1.2   Viewing Information across Disparate Systems

Users also expressed difficulties when viewing information across disparate systems, such as the hospital prescribing system and the discharge system. Ahmed *et al.* also found that hospitals in England often concurrently used different standalone ePrescribing systems, depending on whether discharge medications and chemotherapy were being prescribed.[38] Use of disparate systems is a risk, and from an organisational perspective, it is important to take steps to minimise any associated errors *e.g.,* putting a local policy or protocol in place to ensure this information is manually re-entered across both systems or that users must confirm checking both systems prior to prescribing chemotherapy. Meanwhile, organisations must demand more from their system vendors in terms of interoperability to drive progress in this area. System vendors and organisations must prioritise interoperability between different stand-alone systems and explore strategies that allow this. While integration may introduce some challenges, such as issues with sharing patient data and the compatibility of data across multiple systems, this should not prevent action. Indeed, input may be required

from policy makers to incentivise progress in this area or to standardise the format of data.[282]

The researcher found issues with warfarin prescribing, which had to be entered in free-text on the system and was felt to be more error prone. The functionality to allow insulin to be prescribed electronically was only implemented 6 years after the ePrescribing system was introduced at the study site as this process was more complex than for other medications. Ahmed *et al.* also found that many inpatient systems did not support the prescribing of a reducing or increasing dose of certain medications, such as warfarin and insulin, and so these often remained on paper.[38] Westbrook *et al.* described two separate hospitals in Australia and similarly reported how certain orders such as heparin infusions, patient controlled analgesia (site A) and variable dose regimens (e.g., titrating courses of steroids), warfarin and patient controlled analgesia (site B) remained on paper charts following the initial implementation of an ePrescribing system.[283] Koppel *et al.* acknowledged how due to issues with electronically charting some medications (e.g., insulin), these medications remained on paper, which can cause confusion and loss of information.[115] These examples demonstrate how sites delay or do not use ePrescribing functionality for some medications, in particular certain high risk medications such as warfarin and insulin, resulting in dual paper and electronic systems been used. System developers and organisations should therefore create simple ways of prescribing variable or asynchronous doses in a standardised way on the system. For example, an electronic medication order could include a drop down menu of different warfarin doses with particular days of the week. Further research should explore and evaluate the design of prescribing functionality for titrating doses to help inform practice.

11.4.1.3   Presentation and Meaning of Symbols

Well-designed symbols and icons offer advantages over text by being quickly and easily recognisable. They can also save space on an otherwise busy screen. However, this thesis uncovered how a number of symbols used in the system were not that obvious to the user. An American Medical Informatics Association (AMIA) task force convened by the AMIA board of directors reviewed the literature on usability in health IT and gathered lessons learned on system usability and human factors from other industries *e.g.,* aviation.*[284]* They recommended having a minimum set of 'design patterns' that were shared and common to different ePrescribing systems, which would be advantageous to users working across

different systems. This could help standardise how users interact with different systems, such that certain workflows *e.g.,* checking whether a patient has a hospital acquired infection, documented in the system become routine.[284] Phansalkar *et al.* evaluated the display of DDI alerts in 14 EHR systems (8 home-grown and 6 commercial) using an instrument that assesses system compliance to human factors principles.[103] One of the assessment criteria under the prioritisation category, asked whether the alert utilised shapes or icons in order to indicate the priority of the alert? (i.e., an inverted triangle to indicate a higher priority level). This study found that only two of the 14 systems appropriately used symbols to indicate the priority level of the DDI, such as a red exclamation point within a stop sign shape for the most serious interaction and an exclamation point with an inverted yellow triangle for lower severity alerts.[103] System developers need to make better use of symbols going forward to aid prioritisation of alerts. The authors also stressed the importance of using such symbols consistently throughout the system e.g., for laboratory warnings.[103] Salman *et al.,* described using participatory icon design, where 78 users from a Turkish hospital were sent a list of clinical tasks that were routinely performed (*e.g.,* nurse observation) and asked to draw an icon which represented that specific task.[285] The most frequently drawn icons were then used within the system as part of this experiment.[285] This work did not evaluate the effectiveness of these icons but it described how users were involved in the design process, which is clearly very important.

11.4.2 Challenges with the Prescribing Process

11.4.2.1   Prescribing Challenges and a 'User-Design' Mismatch

This PhD programme of work also revealed how users sometimes misunderstood certain 'key trigger words' or letters. For example, users assumed that 'O' could be entered for once daily*;* however, the system recognised this as a once only (STAT) dose and so users' recalled situations where medications were not prescribed for the correct course length. Horsky *et al.* investigated a medication dosing error that occurred during the use of a US CPOE system and revealed that users possibly had a different understanding of the meaning of the data label "Total Volume" compared to the system developer. The authors posed that users understood "Total Volume" to mean the total dose that should be administered to a patient compared to the system developers who understood "Total Volume" to mean the total volume of the IV bag that was to be administered to the patient. In this US CPOE system, orders could not be limited by the total volume of fluid prescribed; instead, the user had to

specify a particular stop time, which had a default setting of seven days. This was likely to have contributed to a large overdose of IV potassium chloride being administered to a US patient.[117] Howe *et al.* reviewed patient safety reports documented between 2013-16 from the Pennsylvania Patient Safety Authority database and found that 1,956 (0.11%) of the reported safety events mentioned an EHR vendor and were classed as causing 'possible' patient harm.[286] One example described how one part of a 'thyroid group' test was missed off an order placed on the EHR system because of a *"confusing translation between the physician order and the EHR".[286]* This PhD programme of work also revealed how users found it difficult to recall the 'key trigger words' to identify a specific order set *e.g.,* 'the care of the dying order set'. This poses the question of how organisations assigned 'key trigger words' and how much users were involved in this process? One of the key challenges faced by Wright *et al.* when conducting a study to explore usage patterns of order sets in seven US hospitals was the range of naming conventions used across sites.[287] Similarly, a recommendation from this US study was to share the content of common, approved order sets for specific conditions (*e.g.,* based on a national guideline for the treatment of a myocardial infarction) or for a hospital service (*e.g.,* an order set for all blood tests that a patient should receive on admission) so that they could be used across different sites. Wright *et al.* suggested that these could then be tailored to local needs (*e.g.,* addition or removal of a particular medication according to the hospital protocol). This may also present an opportunity to standardise terminology used across systems. Furthermore, system developers should consider assigning multiple commonly used terms to one order set. This would increase the searchability of certain orders and produce more 'hits', saving the user valuable time when prescribing.

11.4.2.2   Order Sentence Design and Indication-Based Prescribing

Prescribers had difficulties selecting the correct medical product that could be prescribed at a range of doses depending on the indication. One such example was the low molecular weight heparin, tinzaparin, which was used for the prophylaxis and treatment of thromboembolism in medical and surgical patients. One possible suggestion that may prevent errors was for the system to automatically select a syringe of appropriate strength (*i.e.,* 3,500 unit dose syringe) after the prescriber has selected the required dose *e.g.,* 3,500 units. A recent report from the US Food and Drug Administration entitled *Computerised Prescriber Order Entry Medication Safety (CPOEMS) Uncovering and Learning from Issues and Errors* examined the design of order sentences and highlighted some issues with auto-

complete functionality, such as presenting users with inappropriate doses.[127] It would therefore also seem sensible for flexibility to be built into the system for the user to modify the strength in the event that the particular drug was out of stock. The CPOEMS report also referred to an example where the correct units for a non-standard dose could not be selected from the CPOE system because this option was 'greyed out' in the drop down menu.[127] This can frustrate users and result in workarounds such as creating free-text orders. Healthcare organisations should routinely review the types of medications and regimens ordered using free-text orders to identify potential order sentences that may need to be adjusted or included in the ePrescribing formulary. Puaar and Dean Franklin conducted a qualitative study to describe the causes of prescribing errors associated with the use of ePrescribing systems from prescribers' perspectives using Reason's accident causation model.[288] They revealed how order sentences that were not tailored to the patient resulted in rule-based mistakes. For instance, a doctor admitted that they did not use the BNF or refer to a pharmacist as much because they assumed *"that must be the dose"* displayed in the structured order sentence.[288] By incorporating more patient specific information into the decision making algorithms used in the system, it is possible that more appropriate doses are presented for a surgical patient. Chertow *et al.* demonstrated how a renal dosing support system that presented users with an alert, which suggested doses for patients with renal insufficiency, was successful at improving the doses prescribed.[86]

Selection errors in particular can occur when users mistakenly choose an option such as an order sentence from a drop down menu. This type of error can result in significant 10x over and under-dose prescribing errors, with real consequences to patient safety.[120] For instance Jani *et al.* encountered an order for trimethoprim oral twice a day that was prescribed as 2.5mg instead of 25mg for a paediatric patient. This could have resulted in inadequate treatment of an infection and was classified as having a potentially moderate outcome.[186] Shulman *et al.* also identified an error when diamorphine was prescribed using a drop-down menu at a dose of 7mg/kg instead of 7mg; although intercepted, this error could have been potentially fatal with the patient receiving a 70-times overdose.[122] The design of drop down menus that contain order sentences should be carefully considered to prevent juxtaposition errors. For example, one could ensure that look-alike-sound-alike medications are not listed next to each other and that potentially tall man lettering is used.[120, 148] Galanter *et al.* found that alerting providers when a medication was

prescribed for an indication that was not listed in the patient's diagnosis problem list reduced wrong patient orders.[150] Similarly, in a separate study, Galanter *et al.* observed that indication-based alerts intercepted 1.4 errors per 1,000 alerts in a set of 39 commonly confused, similar-sounding medication names (*e.g.,* metoprolol and metoclopramide).[289] With each prescription starting with a diagnosis, Schiff *et al.* suggested that the indication should be entered onto the system, which in turn could inform other forms of CDS such as dosing suggestions.[216] The addition of a drug indication could also help educate patients and their healthcare providers about why a medication has been prescribed, with the potential for more far reaching benefits such as supporting improved medication adherence interventions. The patient's wider healthcare team would also be able to scrutinise and clinically check the prescription knowing why it had been prescribed, rather than having to contact the prescriber or patient for this information.[216]

11.4.2.3   Challenges Associated with Unstructured Orders

The researcher identified discrepancies between the prescribed structured order and the free text comment accompanying the order. Palchuk *et al.* found discrepancies in 16.1% (n=470) of the 2,914 electronic prescriptions reviewed in their study conducted in the ambulatory care setting.[154] For example, dexamethasone 4mg tablets were prescribed as '40mg QAM' (quaque ante meridium, meaning every morning), with a comment to say 'please take 40mgs QAM once a week'. If administered according to the structured order sentence, this error could have resulted in immunosuppression and thus was classified as a potential ADE. Of note, Palchuk *et al.* found that 83.8% (n=394) of the discrepancies identified had the potential to cause an ADE, and 16.8% (n=79) of these were thought to have the potential for a severe ADE that could lead to a hospital admission and/or death. They also discovered that the majority of prescriptions with discrepancies (29.2%, n=137) were complex regimens where the dose may have varied throughout the day or over a period of time. Palchuk *et al.* gave the example of how a reducing course of bupropion (a medication used to support smoking cessation) was prescribed using a structured order of 1 tablet(s) BID (bis in die, meaning twice daily), with free-text instructions to 'start use 1 week prior to tobacco quit attempt. start at 1 tab[let] po (per os, meaning orally) qd (quaque die, meaning four times a day) × 3d (for three days), then bid (bis in die, meaning twice a day)'.[154] Singh *et al.* also reported how pharmacists identified 532 errors (almost 1% of all prescriptions made) where information entered in the structured template, on an ePrescribing system within a tertiary care facility did not match the corresponding free-text comment.[290] The

authors estimated that the risk of discrepancy errors occurring in prescriptions that included a free-text comment was to be around 5%.[290] Similar to Palchuk *et al.,* they found that a comparable proportion of these errors (20% n=112) could have resulted in moderate to severe harm to the patient, and noted how complex orders such as a tapering course of steroids were associated with a higher risk of error.[290] Schiff *et al.* found that clinicians resorted to workarounds to prescribe complex prescriptions that were more difficult to write electronically on the ePrescribing system, such as tapering courses of prednisolone.[105] Due to the inherent risk of errors resulting from discrepancies between structured and unstructured orders, Palchuk *et al.* advocated educating users about the limitations of ePrescribing systems and how these systems can allow conflicting structured orders and free-text orders to be entered.[154]

However, when considering how to prevent discrepancies between the structured order and the free-text comment, one needs to question why free text was required in the first place. Zhou *et al.* suggested that prescribers used the free-text field to speed up the prescribing process, particularly in high pressure situations *e.g.,* when trying to prescribe insulin in urgent care, because finding the correct formulation from a long list of medications was difficult.[80] They also reflected on whether users had resorted to prescribing in free-text because they were misspelling the medication name and so the system could not recognise or suggest a structured order.[80] Zhou *et al.* explored this further and found that over three quarters (75.2%; n= 1,814) of the prescriptions ordered using free-text had an exact name match in the system, *i.e.,* if properly searched using the correct spelling, the prescriber should have been able to prescribe the medication using a structured order.[80] Free-text may also have been used as a way of avoiding the need to enter uncertain information into structured fields. For instance, if a patient did not know what dose or brand of insulin they were taking, the doctor could still prescribe 'insulin' as a free-text order, but without the specifics (brand or dose) required for a structured order.[80] Zheng *et al.* investigated the appropriateness of clinicians' use of 'exit strategies' *i.e.,* the actions taken to avoid use of structured fields on an EHR (*e.g.,* documentation of a clinical problem in free-text instead of using a structured code on the system) and found that 63% (n=153) of medication orders and 72% (n=81) of the patient's documented problems (*e.g.,* Parkinson's disease) were inappropriately entered using free-text when a structured format existed within the system.[291] The authors suggested that clinicians may have lacked an understanding of medical coding and using structured orders, or perhaps had difficulties finding their desired option from the structured medical and medication databases.[291] It is also possible that

clinicians preferred to use free-text when they were less sure about their diagnosis; in this way, they could actually reflect their uncertainty.[291] These studies do not reflect on how it might not be possible for the prescriber to place some orders in a structured way; this programme of work found that free-text prescriptions were often used when there was no structured order sentences available that facilitated the prescribing of a reducing course of steroids or warfarin for example. This is an important consideration as reducing doses are not uncommon, thus system developers need to consider how these might be incorporated in the system. Sittig and Singh developed a set of national patient safety goals for EHRs and noted that because of the risks posed by free-text orders and communication, one goal should be to mandate the use of ePrescribing for all medication orders, lab tests and radiologic tests, and facilitate the coding of information as much as possible so that it can be utilised by the system's CDS functionality.[292] One suggestion offered by a junior doctor interviewed as part of this research was to allow users to select individual daily doses from a drop down menu or provide a structured order template for titrating regimens, whereby the user could enter the starting dose, finishing dose, and intervals, thus allowing the full course to be automatically generated in a structured way.

To the researcher's knowledge, there has been little research that has looked at where, when and how the free-text prescriptions or comments are presented to users and what is the most effective approach, and so this should be investigated further.[80, 154, 290] However, work that has explored the human factors design principles of CDS alerts is likely transferable and suggests that both the placement (*i.e.,* where the box is displayed in relation to the main order information) and visibility (*i.e.,* the font and contrast of the free-text comment box in relation to other 'competing' information on the screen) are important and may serve as a starting point for improvements.[56]

11.4.3 CDS

11.4.3.1   Expand Use of CDS

The hospital's system development team had taken a conservative approach to the implementation of interruptive CDS alerts, recognising the potential for alert fatigue amongst its users. This limited use of interruptive CDS alerts was appreciated by some users, yet criticised by others who called for wider use of CDS to make certain processes safer *e.g.,* prescribing. After entering a set of erroneous test orders in a US study, Schiff *et al.* found

that only 26.6% (n=100) of these orders generated specific warnings in different systems, thus indicated underutilisation of CDS alerts in many US systems.[105] Amato *et al.* reviewed 2,522 error reports from six different sites in the US, between January to December 2013 to identify and classify those related to the use of CPOE.[293] For instance, patients receiving the same drug or a drug in the same therapeutic class accounted for 16.2% (n=222) of all errors in this study and could have been potentially avoided with the use of duplicate dose alerts. Magrabi *et al.* also reviewed incident reports entered in to the US Food and Drug Administration Manufacturer and User Facility Device Experience database and found that the absence of CDS contributed to some of these incidents occurring.[294] For example, alerts were not generated to warn users about mismatches in blood groups.[294]

Studies have also described user overdependence on ePrescribing systems for clinical guidance or information.[256] This programme of work revealed how some users assumed that checks were operational in the system, when in fact they were not. In some cases, a warning was displayed to inform the user that it was not able to perform any checks on a particular medication (*e.g.,* unlicensed or newly added to the formulary). These alerts gave the impression to users that checks were being performed for other types of medications, even though the majority of other alerts had been silenced by the system development team. This finding highlighted some of the unintended consequences of having non-clinical alerts in the system. Wright *et al.* found that an alert was not generated as intended for patients receiving low-molecular weight heparins (an anticoagulant) because the alert build had unintentionally only been set up to fire when an unfractionated heparin was prescribed.[295] Additionally, an alert that recommended reviewing a patient's carbamazepine (an anti-epileptic) levels every year was found to have triggered for all brands of carbamazepine except one.[295] This exception related to a specific brand that had been newly added to the drug formulary since this alert was built and thus, patients who were prescribed this brand could have missed important therapeutic drug monitoring. Malfunctioning alerts were detected by testing, reviewing alert data and alert override reasons, reviewing user reports and conducting demonstrations of the system.[295] This emphasises the need for robust procedures when testing CDS functionality.

11.4.3.1.1   *Drug-Drug interaction alerts*

In particular, this programme of work revealed how users felt CDS could be beneficial for identifying high-risk drug-drug interactions, and/or rare but dangerous interactions.

Phansalkar *et al's.,* list of high priority drug-drug interactions may be a useful starting point for organisations considering what specific CDS drug-drug alerts to implement.[61] The authors identified interacting drug pairs within the medication knowledge base used across two large academic medical centres, and assigned a severity level to them, where level 1 was the most serious, level 2 was of moderate severity and level 3 was the least serious interactions. A refined set of the most serious level 1 alerts (31 candidate DDIs) was then reviewed by an expert panel (n=21). The panel settled on a final list of 15 DDI alerts that should, in their opinion, never be co-prescribed (*e.g.,* selective serotonin reuptake inhibitors (SSRI's) and Monoamine oxidase inhibitors (MAOIs).[61] A second study examined whether these 15 DDI alerts were present in five international EHR systems and found that all 15 only existed in two of the systems tested.[106] Furthermore, the numbers of alerts generated were comparatively low across these systems, with only 4.4% (n=768) triggered in the outpatient US system and none in the Belgian and Korean systems.[106] The inclusion of these alerts into a system is therefore unlikely to contribute to a high volume of alerts and subsequent alert fatigue amongst users.[106] The challenge is determining how to present level 2 DDI alerts, which are more commonly prescribed and may have different effects on patients, depending on their clinical condition. Recent studies have highlighted how there is a lack of standardised guidelines on how DDIs alerts in general were classified in terms of severity in different EHR systems.[59, 106] Cornu *et al.* therefore recommended developing a framework for the standardised evaluation of DDIs to determine their clinical relevance.[106] It may also be useful to have a centralised DDI knowledge base that is managed and updated by experts and that could be used by knowledge bases across different EHR system providers.

Furthermore, moving on from the work conducted by Phansalkar *et al.,* to identify high and low risk DDI alerts for inclusion into an EHR.[61, 62] It may also be useful to undertake a similar exercise for other forms of CDS alerts, such as drug-allergy alerts, drug-laboratory alerts or drug-disease alerts, to identify high, medium and low-severity issues that could inform how they are best presented within the system.

11.4.3.1.2   *Mandatory Fields*

The researcher described how the system displayed a prompt to users to encourage them to add a start and stop date for short courses of antibiotics. In another recent study, CDS functionality appeared to increase pharmacists' awareness of more medication-related

problems related to antibiotic prescribing.[296] Allen *et al.* also found that the introduction of standardised order sets and recording of antibiotic indication and duration fields within the ePrescribing system contributed to fewer days of appropriate antibiotic therapy for adult patients in an ICU ward.[297] Similarly, in another study, prescribers were required to select an approved antimicrobial indication before they could proceed with an order, and the completion of this mandatory field was associated with a reduction in targeted antimicrobial use from 1250 to 988 doses administered per 1000 patient-days per year.[298] This suggests that there may be a role for mandatory fields to ensure stop dates and/or indications for short courses of medications are added.

This research found how some users felt that the introduction of other mandatory fields on the system was not compatible with the usual workflow. Niazkhani *et al.* pointed out how ePrescribing systems, imposed a *"sequential and inflexible order of activities"* on the user, which in some cases did not match the intended workflow or usual practice.[234] Blijleven *et al.* found that sometimes the system required overly specific information to be entered in order to proceed (*e.g.,* the exact type of knee surgery that a patient received several years ago) and explained how sometimes such information was not known to the user.[299]

11.4.3.2   Tailored Alerts

This PhD programme of work revealed how there may be scope to tailor alerts to certain clinical areas or patients. For example, renal dosing alerts could be potentially used to guide clinicians' decision making on a non-renal specialist ward. Recent reports have questioned the safety of boarding patients (patients who are sent to a ward either before they are formally admitted or to a ward that is managed by a different consultant than the patient's main consultant).[300] The 'CDS Five Rights', specify that the most effective CDS should provide the (1) right information to the (2) right individuals, in the (3) right formats through the (4) right channels at the (5) right points of the workflow.[301] Therefore, it is important to consider all individuals involved in the patient care and ensure that alerts are directed towards the most appropriate people.[302] Baysari *et al.* highlighted how junior doctors were often the recipients of CDS alerts during ward rounds, yet senior doctors were making the prescribing decisions without ever seeing these alerts.[303] This emphasises the importance of targeting the right individuals at the right time.[303] Riedmann *et al.* also suggested that it may be beneficial to target alerts towards certain clinicians based on their professional experience, giving the example of a senior cardiologist who may want to see

fewer alerts than a junior cardiologist.[304] However, the impact of this would need to be further investigated and tested, as potentially useful alerts should not be switched off for users who may have benefitted from them. As highlighted in Chapter 9.1.3, one newly qualified doctor felt that drug-drug interaction alerts would not be beneficial on the cardiology ward as most of the routine medications worked in good harmony. This exposed perhaps a rather naïve outlook and highlights the dangers when users are not aware of what they don't know. Indeed, Grizzle *et al.* noted how allowing clinicians to customise their own alerts could be dangerous and raised questions of liability within an organisation.[305] There is considerable literature that supports the finding that CDS alerts are not patient specific enough, which results in large volumes of inappropriate alerts being generated.[55, 64] It is clear that there needs to be better use of information already stored within the system about the patient, to guide CDS generation and development. Evidence suggests that utilising patient specific data into the decision making algorithms, can be beneficial at reducing the alert burden.[73, 306] Cornu *et al.* optimised their Belgian ePrescribing system in the following ways: (a) customisation of the severity of the DDI for different classes and for individual medications within class-class interactions, so that the alerts were more specific to the medication prescribed, (b) a new alert design, (c) the creation of individual screening intervals (*i.e.,* assigning a time period for which the interaction poses a clinical risk), and (d) a follow up process involving a second check by a clinical pharmacist for level 1 alerts. In this way, the severity of the alert was tailored towards the scale of the problem, based on patient specific factors, and the authors found that there was an improvement in alert acceptance (2.2% pre versus 52.4% post context enhanced alerts).[307] Seidling *et al.* estimated that approximately 80% of drug-drug interaction alerts were potentially sensitive to context factors (based on their review of 100 critical DDI alerts)[72] and in a separate study, Seidling *et al.* also developed a CDS algorithm that determined patient specific maximum therapeutic doses and alerts for 170 compounds.[308] The authors found that generating a maximum dosage alert resulted in fewer overdoses being prescribed (4.5% n= 552 pre-intervention and 2.6% n=425 post-intervention). [308] During the design of the alert algorithm, it was interesting how the authors set the maximum dose limits at 30% higher than that set by clinical guidelines to reduce unnecessary alerts as a result of slight deviations.[308] Those involved in designing alerts should carefully consider what the maximum dose limit should be set at.

11.4.3.3   Alert Design

Following implementation of the ePrescribing system at the study site, certain physical clues (*e.g.,* a warfarin chart at the end of the patent's bed) were no longer visible. Instead, alerts were added to the system, to remind users to review the patient's INR. If a patient had a significantly elevated INR, alerts could also be sent to more than one healthcare professional e.g., an anticoagulation nurse specialist or pharmacist. However, the alerts at the study site were not found to be particularly useful, with the warfarin review alert presented to the user when they first entered the patient's electronic medical record (which could be for any purpose) rather than the patient's specific medication record (where medication changes are made), which may have been more successful. Bates *et al.* developed Ten Commandments for effective CDS, which included how these systems should (1) anticipate the needs of the user in real time and (2) fit into the users' workflow.[309] The authors emphasised the importance of delivering information at the appropriate time, which in turn increased the likelihood of tasks being performed.[309] Miller *et al.* also described the philosophy behind the design of the Vanderbilt hospital's CPOE system, and stressed the importance of accurately timing the alerts to the situation. They explained how alerts that highlighted a contraindication between two drugs were most appropriately displayed on first selecting the potentially contraindicated drug, rather than after the full order (including selection of a drug dose and frequency) has been finalised. A study in primary care that observed 112 GP consultations suggested that even presenting alerts at the point of drug selection may be too late, as by this stage the GP might have already discussed with the patient what they were intending to prescribe even before they placed the order on the ePrescribing system.[310] Hayward *et al.* recommended that information to inform the decision making should be provided far earlier *i.e.,* when the GP is first considering prescribing.[310] They also suggested that certain information about the patient *e.g.,* allergies should be presented on summary pages and visible at all times.[310] This would benefit healthcare providers that review the patient's record prior to seeing them.

Alerts should also visually present the users with the severity of the problem.[104] Horsky *et al.* suggested classifying alerts into two or three severity levels such as "critical", "significant" and "caution" and be colour coded.[311] Alerts should also facilitate the user taking appropriate action from that alert, for instance, providing a direct link to the warfarin order or an alternative dose. Wright *et al.* found that only one system (out of nine tested) allowed all twelve pre-defined actions to be performed directly from the alert (*e.g.,* write order, edit

current order, edit problem list or cancel existing order).[312] Genes *et al.* developed two CDS pain assessment alerts for geriatric patients, one allowing a 'one-click' pain score update to be obtained directly from the alert.[313] Participants appreciated this functionality with one doctor commenting on how: *"before, you would click on the vitals and there would be 800 different boxes to check so it always takes a long time to find the pain assessment. So I liked that it is very easy to see the button and it takes you only to the pain scale"*.[313] Horsky *et al.* noted how*: "the overall perceived difficulty of interaction with a system is directly related to the number of clicks required"* therefore any reduction in effort for the user to search for information, navigate the system and complete a specific task will contribute to improved usability.[311] Hanna et al., also discussed how doctors complained that there were too many 'mouse clicks' and PIN entries to carry out the intended action in one ePrescribing system.[314] Phansalkar *et al.* advise that the corrective action suggested by an alert should be easy to perform.[56]

11.4.4 Customisation to Improve Efficiency and Safety

11.4.4.1   Customisation of the Medication and Patient List

The first of Bates and colleagues' ten commandments for effective CDS was: *"Speed Is Everything".*[309] Users at the study site customised the 'Medication and Patient Lists' so that they could access certain pieces of information quicker. According to Sopan *et al.* users tend to find their target faster from a shorter list and are more likely to miss it from within a long list.[315] They recommended restricting clinicians' view to only those patients who they were caring for filtering the list *e.g.,* by characteristics such as age or date of admission or the clinical department.[315] Other design changes to the patient list, such as increasing the buffer space between the width and weight of rows were also suggested. Sopan *et al.* predicted that these changes could be achieved with minimal effort and have an impact on patient safety.[315] However, the findings from my research suggested that users often found it difficult to customise the medication list or patient list, even when the functionality existed. In particular, the box that the users needed to click on was very small and not easily recognisable and the process of clicking through multiple drop-down boxes was quite laborious. Designers of ePrescribing systems must carefully consider how tabs and data labels appear and seek the feedback of users to ascertain whether certain tools are clearly visible. Secondly, any action must be acheived using as few clicks as possible so that it does not confuse users or reduce efficiency.[311]

The researcher also obtained a number of different perspectives on how the 'Medication List' should be displayed *e.g.,* chronologically or alphabetically or sorting by active or discontinued medication. Zhang *et al.* noted how: *"users always learn and users are always different",* thus providing users with the option to customise a system could improve their performance.[316]

Phansalkar *et al.* warned that the number of colours used for coding in an environment should be kept to a minimum, ideally fewer than 10.[56] The meaning of any colour must also be obvious or learnable, with minimal training to prevent misinterpretation. Horsky *et al.* suggested that the same colours should be consistently applied throughout the system *i.e.,* if red indicates the highest severity level and orange a lower level, this principle should be used across alerts, reminders and values.[317] A traffic light coding system could be used to distinguish prescribed medications that have stopped as red, suspended items as amber, or currently active as green. However, this may not account for all of the different statuses used in the system, such as 'documented medications' (medications documented within the patient's medication history), which could be confusing and would require further thought. For specific users *e.g.,* those who are colour blind, an alternative method to quickly communicate important information may be needed, for instance using a combined approach which incorporates symbols as well as careful consideration of the colour combinations used (good colour pairings include any dark colour with white).[318]

11.4.4.2 Efficiency and Identification of High Risk Patients: The role of the Pharmacy Task List

Some may argue that pharmacy staff should review every hospitalised patient's medication on a daily basis. This is often not possible due to other commitments and limited resources. Furthermore, not all patients are likely to benefit from a full pharmacist review *e.g.,* a young patient, who is not taking any medications. The Carter review outlined the need to improve efficiency and productivity in the NHS, recommending that pharmacists and pharmacy technicians spend more time on patient-facing medicines optimisation activities.[36] Therefore, tools that can identify certain high risk patients or individuals who may benefit from a pharmacist's review could help achieve this goal. As discussed in Chapter 8.3, the ePrescribing development team introduced a pharmacy task list with users highlighting issues around the tool's sensitivity and specificity of included tasks.

A more robust tool that could effectively predict risk and prioritise hospital inpatients according to where pharmacist intervention is needed, is likely to be incredibly useful both at the study site and across the NHS. Falconer *et al.* developed and validated an electronic assessment risk tool for clinical pharmacist interventions in New Zealand.[319] They identified 38 'flags' that were used to grade risk in patients and found that those classed as 'high risk' had a significantly higher number of unintentional medication discrepancies than those who were classed as medium or low risk. Examples of 'flags' included patients who were prescribed more than eight admission medicines, those aged over 75, and had been readmitted within 30 days. However, this study failed to demonstrate a statistically significant link between some flags and medication discrepancies, possibly owing to the small sample size.[319] Hickson *et al.* developed a non-electronic pharmaceutical assessment screening tool (PAST), which required the pharmacist to manually assign a patient acuity level (PAL) to inpatients.[320] However, 43% (n=15) of patients reviewed had a pharmacist documented acuity level that did not adhere to the pharmacy department's patient acuity screening tool's guidance, which suggests that the tool needed further refinement.[320] It was also possible that senior pharmacists perceive risk differently and future work should focus on finding agreement amongst pharmacists i.e., where all patients would be assigned a high PAL score because of their condition.[320]

11.4.4.3 Changes in Practice: Insulin ePrescribing

The introduction of Insulin ePrescribing by the hospital system development team resulted in several changes in practice *e.g.,* the ability to review blood glucose levels and prescribe insulin remotely; the advantages and disadvantages of these changes were discussed in Chapter 8.2. Campbell *et al.* also identified changes in practices as an unintended consequence of CPOE. In particular, they found issues with 'STAT' orders (orders to be given immediately) in general, which were often missed by the nurse with potential consequences for the patient. In these cases the prescriber failed to verbally communicate to the nurse that the order had been made as they were under the impression that the nurse would see and act upon it straight away because the order had been made on the system.[120] In other words, the system gave the *'illusion of communication'.*[120] There is a still an important role for verbal communication among staff when ePrescribing systems are used and this should be emphasised to users.[120] Electronic whiteboards could also provide a visual clue to nurses of patients who have been prescribed a new 'STAT' order and research should investigate the effectiveness of this approach. My research revealed how the introduction of

insulin ePrescribing also brought about a change in prescribing practice, with the daily re-prescribing of insulin now replaced with a continuous prescription for the patient, which again had advantages and disadvantages. The US Department of Health and Human Services' Office of the National Coordinator for Health Information Technology (ONC) stipulated that system vendors must conduct formal usability testing of EHR functionality, which should include at least 15 end-user representatives; however, Ratwani *et al.* found that only 9 (22%) of the 41 vendors included in their study used at least 15 participants with clinical backgrounds, 1 vendor used no clinical participants, and 7 (17%) used no physician participants.[126] System developers must clearly improve here.

11.4.5 User Training on Electronic Prescribing Systems: Multiple Schools of Thought

11.4.5.1 Practical Exercises and Clinical Scenarios

The researcher identified a range of ways in which users were trained on how to use ePrescribing systems. There appeared to be a lack of consensus amongst interviewees about what the best way to train users was, and how training could be more effectively and efficiently delivered to users across a hospital Trust. Borycki *et al.* developed an EHR portal system, which provided healthcare professional students access to different EHRs in a simulated environment.[247] This included granting fourth year medical students access to dummy patient cases during problem based learning sessions; students felt that this exposure had been useful and suggested use of such a system earlier in their studies.[247] Simulation training also gives users immediate feedback about how they are using the system and can be designed in a more standardised way with set learning objectives.[321]

Arnold and Fuller described the use of a 'simulation module' that was modelled on problematic interface design features of an EHR system.[322] This module presented users with a 'storyline' or scenario that was based on recovering from an error made by a fictional colleague. This gave them exposure to contributing factors to that error (*e.g.,* a drop down menu).[322] One site in particular had specifically designed the training exercises to mimic a user's normal workflow *i.e.,* starting with admitting a patient, prescribing medications, ordering blood tests and writing a discharge prescription. Fowler-Byers and White suggested that ePrescribing training should reflect the same tools, screens and processes that are used

in the particular care setting.[323] Pantaleoni *et al.* also described the use of training themes that were designed according to the healthcare provider's role; some users *"greatly appreciated that [the trainer] adapted content to my [their] experience level"* and thanked the trainers for delivering material that was *"specific to psych [psychology]"*.[324] This emphasised the need to ensure that the training was clinically relevant. Some hospital Trusts ensured that their training staff were also clinically trained, and where possible would match the trainer to the user *i.e.,* a nurse would ideally train other nurses on the system. Role specific trainers are more likely to have a deeper understanding of the specific tasks and problems that other users from a similar profession may encounter during use of the system. Stevens *et al.* described an alternative approach whereby fourth-year medical students were given comprehensive training over a six weeks course and payment to train doctors on a new EHR system being implemented in a US Hospital.[325] The medical students found the experience incredibly positive, as it allowed them to develop teaching skills and use the system. The hospital doctors were also very receptive and scored the trainers extremely well on a post-training survey.[325] This approach may be transferable to UK hospitals and could offer a cost-effective approach to delivering role-specific training.

11.4.5.2 Workforce Training Demands

Healthcare organisations need to ensure that all their staff are competent at using IT systems both now and in the future. The researcher found that certain users (*e.g.,* locum doctors) at some hospitals did not receive any formal training on the system. Studies have shown that insufficient training on an ePrescribing system can contribute to errors.[105, 192] People often have very different learning styles or availability to attend training, which may necessitate the use of a combined strategy.[250] e-learning has been used to deliver training *en-masse*, at a flexible time and location for different users. The material would be standardised and thus delivered consistently, time and time again. However, there is a lack of good quality research that explores how users should be trained on how to use healthcare IT systems, including ePrescribing systems.[326] Whilst e-learning offers benefits, there may be some barriers to using it as the sole training approach. For instance, there were significant costs associated with developing and maintaining software and ensuring that there was sufficient and appropriate hardware to allow users to complete e-learning.[327] Further work is therefore needed to judge the success and acceptability of using e-learning and whether it may be more effective as preparatory training before users receive classroom based sessions or as part of top-up or refresher training. Further work is also needed to

determine the best way to measure users' competency and understanding of using ePrescribing systems. Each of the four hospital sites included in this programme of work had taken a different approach to assessment, with some conducting no assessments to others requiring a mandatory assessment to be completed with a 90% pass mark before using the 'live' system.

11.4.5.3   Informal Training

Ward based training helped users develop a deeper understanding of the ePrescribing system. A report from the Agency for Healthcare Research and Quality described the experiences of grantees who had implemented inpatient CPOE systems and how users valued having access to super users or members of the implementation team to answer questions.[328] Yuan *et al.* also recognised the influence super-users had on their peers and in their study compared super users who had either volunteered for the position with those who had been nominated by their manager because they were considered to be the most 'technologically savvy'.[329] The authors found that super users who had volunteered to perform the role used more 'effort-intensive behaviours' to support the implementation process, for example proactively asking staff if they needed any help and regularly shared information about the EHR with their colleagues. In contrast, the super users who had been nominated by their seniors were more reactive and did not provide as much detail about why the system worked in a certain way.[329] Yuan *et al.* described how some users appeared to be burdened by their training role, thus it is important to consider the additional strain and fatigue that this role may place on them in different clinical settings.[329]

11.5 Recommendations

This research has identified a number of key recommendations that apply to system developers, hospital organisations, users, policy makers and researchers. These recommendations fall under three main areas: the system design, CDS and training approaches, and are presented in Table 10 and discussed further in section 11.5.

Table 10: Recommendations from this PhD programme of work related to the system design, CDS and training approaches

The System Design	
Responsible Person(s)	Recommendation
System developers	The 'Medication List' view should allow users to see all medications that the patient is/ has been prescribed on one screen, including the status (*e.g.,* whether it is active, suspended or discontinued etc.).
System developers	A patient's blood test results should be visible on one screen and the user should be able to customise how this information is presented *e.g.,* vertically or horizontally.
System developers	Words or phrases in data labels should not be truncated. If shortened, it should be possible to view the full word or phrase by 'hovering' over the data label.
Hospital organisations	The risks associated with using disparate systems should be identified, eliminated (*e.g.,* better integration) and reduced (*e.g.,* education).
System developers	Interoperability between standalone systems needs to be improved. .
System developers; researchers; policy makers	Similar design principles for symbols and icons should be used consistently across systems and further investigated.
System developers; hospital organisations	Users should be allowed to develop a personalised patient list that can be filtered by age, clinical area and/or admission date.
System developers	Users should be able to increase the height and width between medication or patient lists.
System developers; hospital organisations	Users should be allowed to customise their 'Medication List' either chronologically or alphabetically.
System developers; hospital organisations	Colour should be used consistently and sparingly throughout the system e.g., alert severity level and be easily learnable.
System developers; hospital organisations	Shades of colour should be used to represent changes in certain levels *e.g.,* light red to dark red to reflect an out-of-range result at either end of the scale.

CDS	
System developers; hospital organisations	Systems should recognise variations of a phrase or spelling to help users identify a specific order set.
System developers; Hospital organisations; policy makers	Users should be required to enter the drug indication, which can then generate indication based dosing suggestions.
System developers; hospital organisations	Ensure availability of order sentences with a prescribed dose, formulation and strength, which should be linked to prevent prescribing errors. Users should be able to amend this where appropriate.
System developers	Drop down menus should not be overly long and look-alike-sound-alike medication names should not be listed next to each other. Tall man lettering could potentially be used to prevent the risk of selection errors but further research is needed to support this.
System developers; hospital organisations	Develop structured order sentences for complex medication regimens *e.g.,* titrating courses of steroids and variable daily doses.
System developers; hospital organisations	A mandatory stop date/ review date should be included for certain medications *e.g.,* short courses of electrolytes and antibiotics.
System developers and hospital organisations	Improve the sensitivity and specificity of CDS by incorporating more patient specific information into the decision-making algorithms.
System developers	Alerts should present a concise description of why they have been presented to the user. Alerts should assist the user to complete the required action *e.g.,* presenting a relevant link to a blood test result.
System developers and hospital organisations	Alerts should be assigned a severity level.
System developers; hospital organisations; users; policy makers	Users and clinical experts should be involved in all stages of the system development, and feedback should be sought regarding the impact of the system on workflow.
Hospital organisations	Organisations should carefully consider the best way to display non-clinical alerts to users.
System developers, hospital organisations	Further development and investigation into the use of the pharmacy prioritisation tools.

Approaches to training	
Hospital organisations	All users should receive a minimum level of training, so that they can familiarise and learn to navigate the system and get instant feedback about their use.
Hospital organisations	Clinical scenarios that are used in user training should: (a) reflect the user's usual workflow and (b) describe common errors that can be made when using the system and how one should avoid them.
Hospital organisations	The content of the training material should be tailored to the user's specific role or level of experience.
Hospital organisations	It would be advantageous for the trainer to have a clinical background that matches the user group (e.g., a nurse training a group of nurses).
Hospital organisations	Trainers should be enthusiastic and dedicated.

11.6 Areas of Future Research

This PhD has identified several areas of further research that could improve patient safety, usability of ePrescribing systems and service delivery.

11.6.1 System Design

The design and use of computer technology, and how people interact with this technology is a widely researched area. Further research is needed in three key areas (1) CDS, (2) pharmacy prioritisation tools and (3) paediatric ePrescribing systems.

11.6.1.1   CDS

CDS must be optimised and this programme of work has identified several areas of further research. The wording and phrases used in systems for key trigger words (*e.g.,* the naming of order sets) used within the system needs more consideration. Secondly, the effect of introducing additional DDI alerts on alert overrides, patient outcomes and user satisfaction, across a range of different users in the UK setting also needs to be further investigated. Factors that contribute to alert success (i.e., alert acceptance and action taken by a clinician) and failure (i.e., inappropriate overrides) should be further explored and disseminated. The timing of alerts was recognised as important; this requires a greater understanding of clinical

workflows and user input to determine the most appropriate time for alert presentation. More research is needed to help standardise severity levels of different medication-related CDS alerts across systems.[106]

11.6.1.2   Electronic prioritisation tools

The acceptability of a user-task list or 'prioritisation tool' for clinical users including pharmacy, medical and nursing staff should be investigated. Such a tool could help organisations audit practice, enable users to organise their work remotely and may also result in fewer interruptive alerts, if issues could be documented on a 'log' rather than disturbing the user's workflow. The pharmacy task list developed and employed at the study site was appreciated by users but further improvements are needed; additional indicators need to be identified and included into the task list to improve the specificity and sensitivity of the tool. Furthermore, patients should be assigned an acuity level that will help users identify high-risk patients and inform prioritisation of pharmacy services. The effect of this on patient outcomes, cost effectiveness and user satisfaction should be explored.

11.6.1.3   Paediatric ePrescribing systems

As the systematic review in chapter 4 highlighted, unintended consequences have occurred during the use of paediatric systems. There has been little research exploring the impact of ePrescribing systems on the rates of medication errors in the UK. Therefore, further research should address this knowledge gap and help to further explore issues with paediatric system design and functionality.

11.6.2 Training

The training of users of ePrescribing systems has been under researched. This programme of work suggested that clinically experienced trainers should ideally be matched with their user group. However, this was often impractical due to a lack of resources. The use of healthcare professional students to train staff should be considered and further explored. E-learning offers a potentially efficient way of training large volumes of users; however, further research is needed to understand the advantages and disadvantages associated with using this approach and how it should be employed (i.e., as a sole approach or as part of a blended learning strategy). Related to this, the training needs of different users (including locum staff)

needs to be further investigated, as well as the best ways of ensuring that staff are competent.

11.7 Concluding Remarks

This thesis presents a PhD programme of work, comprising of a series of systematic literature reviews (Chapters 2 to 5), and qualitative methods to explore staff experiences of using an ePrescribing system in one UK hospital Trust (Chapters 6 to 10). This led onto a follow-on pilot study, which examined how users were trained to use ePrescribing systems across four NHS hospital Trusts (Chapter 10). As a result, this research has highlighted various issues with the design and usability of ePrescribing systems. Human factors design principles should be considered during the design and ongoing development of these systems and users should be involved throughout. The researcher encountered issues with the 'Medication List' and how information was presented. She also gained an understanding of the challenges users faced when viewing blood test results and using certain symbols. Ultimately, such issues can result in workarounds or pose a risk to patient safety. In particular, this programme of work uncovered benefits and challenges associated with the use of order sentences, order sets and favourite lists. There appeared to be a lack of user involvement in the design and development of the system. Interruptive CDS had been introduced conservatively at this study site; some users found that this was good because it did not disrupt their workflow. However, other users called for additional CDS to be implemented to reduce the risk of errors occurring in the future. Further research may guide what CDS to include and how this should be presented.

Future research should also consider the development of digital tools that can support healthcare professionals to target their services towards patients who would benefit from their input the most.

Finally, this PhD programme of work explored the training approaches used to train users on ePrescribing systems. Several approaches were identified, yet the question of how we should best train users to use ePrescribing systems remains unanswered. This training should really be introduced at an undergraduate level, thus preparing users for using such systems safely and effectively in the future.

References

1.   National Patient Safety Agency, *Safety in Doses: Improving the use if medicines in the NHS* (2007) National Reporting and Learning Service.

2.   Pirmohamed, M., James, S., Meakin, S., et al., *Adverse drug reactions as cause of admission to hospital: prospective analysis of 18 820 patients.* BMJ, 2004. **329**(7456): p. 15-9.

3.   Kohn, L.T., J. Corrigan, and M.S. Donaldson, *To err is human : building a safer health system*. 2000, Washington, D.C., Great Britain: National Academy Press.

4.   James, J.T., *A new, evidence-based estimate of patient harms associated with hospital care.* J Patient Saf, 2013. **9**(3): p. 122-8.

5.   Elliott R, C.E., Campbell F, Jankovic D, et al., *Prevalence and Economic Burden of Medication Errors in The NHS in England. Rapid evidence synthesis and economic analysis of the prevalence and burden of medication error in the UK.* Policy Research Unit in Economic Evaluation of Health and Care Interventions. 2018, Universities of Sheffield and York.

6.   Howard, R.L., Avery, A.J., Slavenburg, S., et al., *Which drugs cause preventable admissions to hospital? A systematic review.* Br. J. Clin. Pharmacol, 2007. **63**(2): p. 136-147.

7.   Dean, B., N. Barber, and M. Schachter, *What is a prescribing error?* Qual Health Care, 2000. **9**(4): p. 232-7.

8.   Lewis, P.J., Dornan, T., Taylor, D., et al., *Prevalence, incidence and nature of prescribing errors in hospital inpatients: a systematic review.* Drug Saf, 2009. **32**(5): p. 379-89.

9.   Dean, B., *Learning from prescribing errors.* BMJ Qual. Saf, 2002. **11**(3): p. 258-260.

10.   Bates, D.W., Boyle, D.L., Vander Vliet, M.B., et al., *Relationship between medication errors and adverse drug events.* J Gen Intern Med, 1995. **10**(4): p. 199-205.

11.   Bates, D.W., Cullen, D. J., Laird, N., et al., *Incidence of adverse drug events and potential adverse drug events. Implications for prevention. ADE Prevention Study Group.* JAMA, 1995. **274**(1): p. 29-34.

12.   Reason, J., *Human Error*. 1990, Cambridge, UK: Cambridge University Press.

13.   Reason, J., *Human error: models and management.* BMJ, 2000. **320**(7237): p. 768-770.

14.   Dornan, T.A., Heathfield, H., Lewis, P., et al., *An in Depth Investigation into Causes of Prescribing Errors by Foundation Trainees in Relation to their Medical Education. EQUIP Study.* A Report to the General Medical Council, 2009.

15.   Leape, L.L., Bates, D.W., Cullen, D.J., et al., *Systems analysis of adverse drug events.* JAMA, 1995. **274**(1): p. 35-43.

16.   Dean, B., Schachter, M., Vincent C., et al., *Causes of prescribing errors in hospital inpatients: a prospective study.* Lancet, 2002. **359**.

17.   Tully, M.P., Ashcroft, Darren M., Dornan, T., et al., *The Causes of and Factors Associated with Prescribing Errors in Hospital Inpatients.* Drug Saf, 2009. **32**(10): p. 819-836.

18.   Avery, T., Barber, N., Ghaleb, M., et al., *Investigating the prevalence and causes of prescribing errors in general practice: The PRACtICe Study (PRevalence And Causes of prescrIbing errors in general practiCe)*, A report for the GMC, 2012.

19.   Slight, S.P., Howard, R., Maisoon, G., et al., *The causes of prescribing errors in English general practices: a qualitative study.* Br. J. Gen. Pract, 2013. **63**(615): p. e713-e720.

20.   Robertson, A., Cresswell, Kathrin., Takian, A., et al., *Implementation and adoption of nationwide electronic health records in secondary care in England: qualitative analysis of interim results from a prospective national evaluation.* BMJ, 2010. **341**.

21.   Bates, D.W., *Using information technology to reduce rates of medication errors in hospitals.* BMJ, 2000. **320**(7237): p. 788-791.

22.   Bates, D.W., Leape, L.L., Cullen, D.J., et al., *Effect of computerized physician order entry and a team intervention on prevention of serious medication errors.* JAMA, 1998. **280**(15): p. 1311-1316.

23.   Kaushal, R., et al., *Electronic prescribing improves medication safety in community-based office practices.* J Gen Intern Med, 2010. **25**(6): p. 530-6.

24.   Kaushal, R., K.G. Shojania, and D.W. Bates, *Effects of computerized physician order entry and clinical decision support systems on medication safety: a systematic review.* Arch Intern Med, 2003. **163**(12): p. 1409-16.

25.   Ammenwerth, E., Schnell-Inderst, P., Machan, C., et al., *The effect of electronic prescribing on medication errors and adverse drug events: a systematic review.* J Am Med Inform Assoc, 2008. **15**(5): P. 585-600

26.   Radley, D.C., Wasserman, M. R., Olsho, L. E. W. et al., *Reduction in medication errors in hospitals due to adoption of computerized provider order entry systems.* J Am Med Inform Assoc 2013. **20**(3): p. 470-476.

27.   Nuckols, T.K., Smith-Spangler, C., Morton, S.C., et al., *The effectiveness of computerized order entry at reducing preventable adverse drug events and medication errors in hospital settings: a systematic review and meta-analysis.* Syst Rev, 2014. **3**: p. 56.

28.   British Medical Association and Pharmaceutical Society of Great Britain., *British national formulary 72*.

29.   van Rosse, F., Maat, B., Rademaker, C.M., et al., *The effect of computerized physician order entry on medication prescription errors and clinical outcome in pediatric and intensive care: a systematic review.* Pediatrics, 2009. **123**.

30.   Avery, A.J., Rodgers, S., Cantrill, J.A., et al., *A pharmacist-led information technology intervention for medication errors (PINCER): a multicentre, cluster randomised, controlled trial and cost-effectiveness analysis.* The Lancet. 2012. **379**(9823): p. 1310-1319.

31.   NHS Connecting for Health, *ePrescribing Functional Specification for NHS Trusts* 2007

32.   Department of Health, *Jeremy Hunt challenges NHS to go paperless by 2018*. 2013.

33.   National Health Service, *Five Year Forward View*. 2014.

34.   NHS England, *Safer Hospitals, Safer Wards: Achieving an Integrated Digital Care Record*. 2013.

35.   NHS England, *The Integrated Digital Care Fund: Achieving integrated health and care records.* 2014.

36.   An independent report for the Department of Health by Lord Carter of Coles. *Operational productivity and performance in English NHS acute hospitals: Unwarranted variations*, 2016.

37.   Crowe, S., Cresswell, K., Avery, A.J., et al., *Planned implementations of ePrescribing systems in NHS hospitals in England: a questionnaire study.* JRSM Short Rep, 2010. **1**(4): p. 33.

38.   Ahmed, Z., McLeod, M.C., Barber, N., et al., *The Use and Functionality of Electronic Prescribing Systems in English Acute NHS Trusts: A Cross-Sectional Survey.* PLOS ONE, 2013. **8**(11): p. e80378.

39.   Schade, C.P., Sullivan, F.M., de Lusignan, S., et al., *e-Prescribing, Efficiency, Quality: Lessons from the Computerization of UK Family Practice.* J Am Med Inform Assoc. 2006. **13**(5): p. 470-475.

40. Pedersen, C.A., P.J. Schneider, and D.J. Scheckelhoff, *ASHP national survey of pharmacy practice in hospital settings: Prescribing and transcribing—2016.* Am J Health Syst Pharm, 2017. 74(17):1336-1352.

41. Slight, S.P. and E.S. Berner, *Meaningful Use of Electronic Health Records: Experiences From the Field and Future Opportunities.* JMIR Med Inform. 2015. **3**(3): p. e30.

42. Henderson, J., H. Britt, and G. Miller, *Extent and utilisation of computerisation in Australian general practice.* Med J Aust, 2006. **185**(2): p. 84-7.

43. ePrescribing Toolkit for NHS Hospitals. 2017 [Available from: http://www.eprescribingtoolkit.com/.

44. Kruse, C.S. and K. Goetz, *Summary and Frequency of Barriers to Adoption of CPOE in the U.S.* J Med Syst. 2015. **39**(2): p. 15.

45. Poon, E.G., Blumenthal, D., Jaggi, T., et al., *Overcoming Barriers To Adopting And Implementing Computerized Physician Order Entry Systems In U.S. Hospitals.* Health Aff, 2004. **23**(4): p. 184-190.

46. Kuperman, G.J., Bobb, A., Payne., et al., *Medication-related clinical decision support in computerized provider order entry systems: a review.* J Am Med Inform Assoc, 2007. **14**(1): p. 29-40.

47. Bright, T.J., Wong, A., Dhurjati, R., et al., *Effect of clinical decision-support systems: a systematic review.* Ann Intern Med, 2012. **157**(1): p. 29-43.

48. Durieux, P., Trinquart, L., Colombet, I., et al., *Computerized advice on drug dosage to improve prescribing practice.* Cochrane Database Syst Rev, 2008 **16**(3): p. Cd002894.

49. Pearson, S.A., Moxey, A., Robertson, J., et al., *Do computerised clinical decision support systems for prescribing change practice? A systematic review of the literature (1990-2007).* BMC Health Serv Res, 2009. **9**: p. 154.

50. Kawamoto, K., Hongsermeier, T., Wright, A., et al., *Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success.* BMJ, 2005. **330**(7494): p. 765.

51. Garg, A.X., Adhikari, N. K., McDonald, H., et al., *Effects of computerized clinical decision support systems on practitioner performance and patient outcomes: a systematic review.* JAMA, 2005. **293**(10): p. 1223-38.

52. Kaushal, R., Jha, A. K., Franz, C., et al., *Return on investment for a computerized physician order entry system.* J Am Med Inform Assoc, 2006. **13**(3): p. 261-6.

53. Wolfstadt, J.I., Gurwitz, J. H., Field, T.S., et al., *The effect of computerized physician order entry with clinical decision support on the rates of adverse drug events: a systematic review.* J Gen Intern Med, 2008. **23**(4): p. 451-8.

54. Ash, J.S., Sittig, Dean F., Campbell, E.M., et al., *Some Unintended Consequences of Clinical Decision Support Systems.* AMIA Annu Symp Proc, 2007. p. 26-30.

55. van der Sijs, H., Aarts, J., Vulto, A., et al., *Overriding of Drug Safety Alerts in Computerized Physician Order Entry.* J Am Med Inform Assoc, 2006. **13**(2): p. 138-147.

56. Phansalkar, S., Edworthy, J., Hellier, E., et al., *A review of human factors principles for the design and implementation of medication safety alerts in clinical information systems.* J Am Med Inform Assoc, 2010. **17**(5): p. 493-501.

57. Tolley, C.L., Slight, S.P., Husband, A.K., et al., *Improving medication-related clinical decision support.* Am J Health Syst Pharm, 2018. **75**(4): p. 239-246.

58. Lapane, K.L., Waring, M. E., Schneider, K. L., et al., *A mixed method study of the merits of e-prescribing drug alerts in primary care.* J Gen Intern Med, 2008. **23**(4): p. 442-6.

59. McEvoy, D.S., Sittig, D.F., Hickman, T., et al., *Variation in high-priority drug-drug interaction alerts across institutions and electronic health records.* J Am Med Inform Assoc., 2016. **24**(2): 331–338.

60. Paterno, M.D., Maviglia, S.M., Gorman, P.N., et al., *Tiering Drug–Drug Interaction Alerts by Severity Increases Compliance Rates.* J Am Med Inform Assoc., 2009. **16**(1): p. 40-46.

61. Phansalkar, S., Desai, A.A., Bell, D., et al., *High-priority drug-drug interactions for use in electronic health records.* J Am Med Inform Assoc, 2012. **19**(5): p. 735-43.

62. Phansalkar, S., van der Sijs, H., Tucker, a.D., et al., *Drug-drug interactions that should be non-interruptive in order to reduce alert fatigue in electronic health records.* J Am Med Inform Assoc, 2013. **20**(3): p. 489-93.

63. Mille, F., Schwartz, C., Brion, F., et al., *Analysis of overridden alerts in a drug-drug interaction detection system.* Int J Qual Health Care, 2008. **20**(6): p. 400-5.

64. Slight, S.P., Seger, D.L., Nanji, K.C., et al., *Are we heeding the warning signs? Examining providers' overrides of computerized drug-drug interaction alerts in primary care.* PLoS One, 2013. **8**(12): p. e85071.

65. Nanji, K.C., Slight, S.P., Seger, D.L., et al., *Overrides of medication-related clinical decision support alerts in outpatients.* J Am Med Inform Assoc, 2014. **21**(3): p. 487-91.

66. Russ, A.L., Zillich, A.J., McManus, M.S., et al., *A human factors investigation of medication alerts: barriers to prescriber decision-making and clinical workflow.* AMIA Annu Symp Proc. **2009**: p. 548-52.

67. Seidling, H.M., Phansalkar, S., Seger, D.L., et al., *Factors influencing alert acceptance: a novel approach for predicting the success of clinical decision support.* J Am Med Inform Assoc, 2011. **18**(4): p. 479-84.

68. Taegtmeyer, A.B., Kullak-Ublick, G. A. Widmer, N., et al., *Clinical usefulness of electronic drug-drug interaction checking in the care of cardiovascular surgery inpatients.* Cardiology, 2012. **123**(4): p. 219-22.

69. Coleman, J.J., van der Sijs, H., Haefeli, W.E., et al., *On the alert: future priorities for alerts in clinical decision support for computerized physician order entry identified from a European workshop.* BMC Med Inform Decis Mak. 2013. **13**(1): p. 1-8.

70. Lin, C.-P., Payne, T.H., Nichol, W.P., et al., *Evaluating Clinical Decision Support Systems: Monitoring CPOE Order Check Override Rates in the Department of Veterans Affairs' Computerized Patient Record System.* J Am Med Inform Assoc. 2008. **15**(5): p. 620-626.

71. Strom, B.L., Schinnar, R., Aberra, F., et al., *Unintended effects of a computerized physician order entry nearly hard-stop alert to prevent a drug interaction: a randomized controlled trial.* Arch Intern Med, 2010. **170**(17): p. 1578-83.

72. Seidling, H.M., Klein, U., Schaier, M., et al., *What, if all alerts were specific - estimating the potential impact on drug interaction alert burden.* Int J Med Inform, 2014. **83**(4): p. 285-91.

73. Duke, J.D. and D. Bolchini, *A Successful Model and Visual Design for Creating Context-Aware Drug-Drug Interaction Alerts.* AMIA Annu Symp Proc, 2011. **2011**: p. 339-348.

74. Duke, J.D., X. Li, and P. Dexter, *Adherence to drug-drug interaction alerts in high-risk patients: a trial of context-enhanced alerting.* J Am Med Inform Assoc, 2013. **20**(3): p. 494-8.

75. Isaac, T., Weissman, J. S., David, R.B., et al., *Overrides of medication alerts in ambulatory care.* Arch Intern Med, 2009. **169**.(3) p.305-11

76. Jani, Y.H., N. Barber, and I.C. Wong, *Characteristics of clinical decision support alert overrides in an electronic prescribing system at a tertiary care paediatric hospital.* Int J Pharm Pract, 2011. **19**(5): p. 363-6.

77. Gonzalez-Gregori, R., Dolores Hernández Fernandez De Rojas, M., López-Salgueiro, R., et al., *Allergy alerts in electronic health records for hospitalized patients.* Ann Allergy Asthma Immunol, 2012. **109**(2): p. 137-40.

78. Weingart, S.N., Massagli, M., Cyrulik, A., et al., *Assessing the value of electronic prescribing in ambulatory care: a focus group study.* Int J Med Inform, 2009. **78**(9): p. 571-8.

79. Fernando, B., Morrison, Z., Kalra, D., et al., *Approaches to recording drug allergies in electronic health records: qualitative study.* PLoS One, 2014. **9**(4): p. e93047.

80. Zhou, L., Mahoney, L.M., Shakurova, A., et al., *How many medication orders are entered through free-text in EHRs?--a study on hypoglycemic agents.* AMIA Annu Symp Proc, 2012. **2012**: p. 1079-88.

81. Slight, S.P., Beeler, P.E., Seger, D.L.., et al., *A cross-sectional observational study of high override rates of drug allergy alerts in inpatient and outpatient settings, and opportunities for improvement.* BMJ Qual Saf, 2017. **26**(3): p. 217-225.

82. Hsieh, T.C., Kuperman, g.J., Jaggi, T., et al., *Characteristics and consequences of drug allergy alert overrides in a computerized physician order entry system.* J Am Med Inform Assoc, 2004. **11**(6): p. 482-91.

83. Topaz, M., Seger, D.L., Slight, S.P., et al., *Rising drug allergy alert overrides in electronic health records: an observational retrospective study of a decade of experience.* J Am Med Inform Assoc, 2015. 23(3):601-8.

84. Gillaizeau, F., Chan, E., Trinquart, L., et al., *Computerized advice on drug dosage to improve prescribing practice.* Cochrane Database Syst Rev, 2013(11): p. Cd002894.

85. Killelea, B.K., Kaushal, R., Cooper, M., et al., *To what extent do pediatricians accept computer-based dosing suggestions?* Pediatrics, 2007. **119**(1): p. e69-75.

86. Chertow, G.M., Lee, J., Kuperman, G.J., et al., *Guided medication dosing for inpatients with renal insufficiency.* JAMA, 2001. **286**(22): p. 2839-44.

87. Peterson, J.F., Kuperman, G.J., Shek, C., et al., *Guided prescription of psychotropic medications for geriatric inpatients.* Arch Intern Med, 2005. **165**(7): p. 802-7.

88. Sellier, E., Colombet, I., Sabatier, B., et al., *Effect of alerts for drug dosage adjustment in inpatients with renal insufficiency.* J Am Med Inform Assoc, 2009. **16**(2): p. 203-10.

89. Peterson, J.F., Rosenbaum, B. P., Waitman, L.R., et al., *Physicians' response to guided geriatric dosing: initial results from a randomized trial.* Stud Health Technol Inform, 2007. **129**(Pt 2): p. 1037-40.

90. Boussadi, A., Caruba, T., Zapletal, E., et al., *A clinical data warehouse-based process for refining medication orders alerts.* J Am Med Inform Assoc, 2012. **19**(5): p. 782-5.

91. Kirkendall, E.S., S.A. Spooner, and J.R. Logan, *Evaluating the accuracy of electronic pediatric drug dosing rules.* J Am Med Inform Assoc, 2014. **21**(e1): p. e43-9.

92. Wachter, Robert., *The Digital Doctor: Hope, Hype, and Harm at the Dawn of Medicine's Computer Age*. 2015, United States: McGraw-Hill Education.

93. Johnson, K.B., Lee, C.K., Spooner, S.A., et al., *Automated dose-rounding recommendations for pediatric medications.* Pediatrics, 2011. **128**(2): p. e422-8.

94. Wetterneck, T.B., Walker, J.M., Blosky, M.A., et al., *Factors contributing to an increase in duplicate medication order errors after CPOE implementation.* J Am Med Inform Assoc, 2011. **18**(6): p. 774-82.

95. The Joint Commission, *Medication Management Standard*: MM.05.01.01, EP.

96. Voils, C.I., B. Sleath, and M.L. Maciejewski, *Patient perspectives on having multiple versus single prescribers of chronic disease medications: results of a qualitative study in a veteran population.* BMC Health Serv Res, 2014. **14**(1): p. 490.

97. Crosson, J.C., Schueth, A.J., Isaacson, N., et al., *Early adopters of electronic prescribing struggle to make meaningful use of formulary checks and medication history documentation.* J Am Board Fam Med, 2012. **25**(1): p. 24-32.

98. Grossman, J.M., Gerland, A., Reed, M.C., et al., *Physicians' experiences using commercial e-prescribing systems.* Health Aff, 2007. **26**(3): p. w393-404.

99.   Rodriguez, R., B. Staley, and R.C. Hatton, *Evaluating incorporation of drug restrictions into computerized drug order entries after transition to an electronic health record.* Hosp Pharm, 2013. **48**(7): p. 568-73.

100.   Fischer, M.A., Vogeli, C., Stedman, M., et al., *Effect of electronic prescribing with formulary decision support on medication use and cost.* Arch Intern Med, 2008. **168**(22): p. 2433-9.

101.   Weinger, M.B., Pantiskas, C., Wiklund, M.E., et al., *Incorporating human factors into the design of medical devices.* JAMA, 1998. **280**(17): p. 1484.

102.   Zachariah, M., Phansalkar, S., Seidling, H.M., et al., *Development and preliminary evidence for the validity of an instrument assessing implementation of human-factors principles in medication-related decision-support systems–I-MeDeSA.* J Am Med Inform Assoc, 2011. **18**. Suppl 1:i62-72.

103.   Phansalkar, S., Zachariah, M., Seidling, H.M., et al., *Evaluation of medication alerts in electronic health records for compliance with human factors principles.* J Am Med Inform Assoc, 2014. **21**(e2): p. e332-40.

104.   Payne, T.H., Hines, L.E., Raymond, C.C., et al., *Recommendations to improve the usability of drug-drug interaction clinical decision support alerts.* J Am Med Inform Assoc. 2015. **22**(6): p. 1243-1250.

105.   Schiff, G.D., Amato, M.G., Eguale, T., et al., *Computerised physician order entry-related medication errors: analysis of reported errors and vulnerability testing of current systems.* BMJ Qual Saf, 2015. **24**(4): p. 264-71.

106.   Cornu, P., Phansalkar, S., Seger, D.L., et al., *High-priority and low-priority drug–drug interactions in different international electronic health record systems: A comparative study.* Int J Med Inform. 2018. **111**: p. 165-171.

107.   van der Sijs, H., Aarts, J., van Gelder, T., et al., *Turning off frequently overridden drug alerts: limited opportunities for doing it safely.* J Am Med Inform Assoc, 2008. **15**(4): p.439-48.

108.   Cox, Z.L., Nelsen, C.L., Waitman, l.R., et al., *Effects of clinical decision support on initial dosing and monitoring of tobramycin and amikacin.* Am J Health Syst Pharm, 2011. **68**(7): p. 624-32.

109.   Tiwari, R., Tsapepas, D.S., Powell, J.T., et al., *Enhancements in healthcare information technology systems: customizing vendor-supplied clinical decision support for a high-risk patient population.* J Am Med Inform Assoc, 2013. **20**(2): p. 377-80.

110.   Cresswell, K.M., Bates, D.W., Williams, R., et al., *Evaluation of medium-term consequences of implementing commercial computerized physician order entry and clinical decision support prescribing systems in two 'early adopter' hospitals.* J Am Med Inform Assoc, 2014. **21**(e2): p. e194-202.

111.   Russ, A.L., Zillich, A.J., McManus, M.S., et al., *Prescribers' interactions with medication alerts at the point of prescribing: A multi-method, in situ investigation of the human-computer interaction.* Int J Med Inform, 2012. **81**(4): p. 232-43.

112.   Long, A.J., Chang, P., Li, Y.C., et al., *The use of a CPOE log for the analysis of physicians' behavior when responding to drug-duplication reminders.* Int J Med Inform, 2008. **77**(8): p. 499-506.

113.   Campion, T.R., Jr., et al., *Characteristics and effects of nurse dosing over-rides on computer-based intensive insulin therapy protocol performance.* J Am Med Inform Assoc, 2011. **18**(3): p. 251-8.

114.   Field, T.S., Rochon, P., Lee, M., et al., *Computerized clinical decision support during medication ordering for long-term care residents with renal insufficiency.* J Am Med Inform Assoc, 2009. **16**(4): p. 480-5.

115.   Koppel, R., Metlay, J.P., Cohen, A., al., *Role of computerized physician order entry systems in facilitating medication errors.* JAMA, 2005. **293**(10): p. 1197-203.

116. FitzHenry, F., Doran, J., Lobo., B., et al., *Medication-error alerts for warfarin orders detected by a bar-code-assisted medication administration system.* Am J Health Sys Pharm, 2011. **68**(5): p. 434-441.

117. Horsky, J., G.J. Kuperman, and V.L. Patel, *Comprehensive Analysis of a Medication Dosing Error Related to CPOE.* J Am Med Inform Assoc, 2005. **12**(4): p. 377-382.

118. Brown, C.L., Reygate, K., Slee, A., et al., *A literature review of the training offered to qualified prescribers to use electronic prescribing systems: why is it so important?* Int J Pharm Pract, 2017. 25(3):195-202.

119. Brown, C.L., Mulcaster, H.L., Triffitt, K.L., et al., *A systematic review of the types and causes of prescribing errors generated from using computerized provider order entry systems in primary and secondary care.* J Am Med Inform Assoc, 2017. 24(2):432-440.

120. Campbell, E.M., Sittig, D.F., Ash, J.S., et al., *Types of Unintended Consequences Related to Computerized Provider Order Entry.* J Am Med Inform Assoc, 2006. **13**(5): p. 547-556.

121. Gandhi, T.K., Weingart, S.N., Seger, A. C., et al., *Outpatient prescribing errors and the impact of computerized prescribing.* J Gen Intern Med, 2005. **20**(9): p. 837-41.

122. Shulman, R., Singer, M., Goldstone, J., et al., *Medication errors: a prospective cohort study of hand-written and computerised physician order entry in the intensive care unit.* Criti Care, 2005. **9**(5): p. R516-R521.

123. Ash, J.S., Sittig, D.F., Dykstra, R., et al., *Exploring the unintended consequences of computerized physician order entry.* Stud Health Technol Inform, 2007. **129**(Pt 1): p. 198-202.

124. Ash, J.S., Sittig, D.F., Poon, E.G., et al., *The extent and importance of unintended consequences related to computerized provider order entry.* J Am Med Inform Assoc, 2007. **14**(4): P. 415–423.

125. Khajouei, R. and M.W. Jaspers, *The impact of CPOE medication systems' design aspects on usability, workflow and medication orders: a systematic review.* Methods Inf Med, 2010. **49**(1): p. 3-19.

126. Ratwani, R.M., Benda, N.C., Hettinger., et al., *Electronic health record vendor adherence to usability certification requirements and testing standards.* JAMA, 2015. **314**(10): p. 1070-1071.

127. Brigham and Women's Hospital (BWH) Center for Patient Safety Research and Practice, *Computerized Prescriber Order Entry Medication Safety (CPOEMS): Uncovering and Learning From Issues,* Brigham and Women's Hospital (BWH) Center for Patient Safety Research and Practice-U.S. Food and Drug Administration (FDA) Computerized Prescriber Order Entry Medication Safety (CPOEMS) Project*,* 2015.

128. Moher, D., Liberati, A., Tetzlaff., et al., *Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement.* BMJ, 2009. **339** :b2535

129. Critical Appraisal Skills Programme (CASP). *CASP Checklist* 2014; Available from: http://media.wix.com/ugd/dded87_29c5b002d99342f788c6ac670e49f274.pdf

130. Mays, N. and C. Pope, *Qualitative Research: Rigour and qualitative research.* BMJ, 1995. **311**(6997): p. 109-112.

131. Caudill-Slosberg, M. and W.B. Weeks, *Case study: identifying potential problems at the human/technical interface in complex clinical systems.* Am J Med Qual, 2005. **20**(6): p. 353-7.

132. Chan, J., Shojania, K.G., Easty, A.C., et al., *Usability evaluation of order sets in a computerised provider order entry system.* BMJ Qual Saf, 2011. **20**(11): p. 932-40.

133. Baysari, M.T., Reckman, M.H., Li, L., et al., *Failure to utilize functions of an electronic prescribing system and the subsequent generation of 'technically preventable' computerized alerts.* J Am Med Inform Assoc, 2012. **19**(6): p. 1003-10.

134. Adelman, J.S., Aschner, J.L., Schechter, C.B., et al., *Evaluating Serial Strategies for Preventing Wrong-Patient Orders in the NICU.* Pediatrics, 2017. **139**(5) e20162863.

135. Savage, I., Cornford, T., Klecun, Ela., et al., *Medication errors with electronic prescribing (eP): Two views of the same picture.* BMC Health Serv Res, 2010. **10**(1): p. 135.

136. Goldman, R.E., C. Dube, and K.L. Lapane, *Beyond the basics: refills by electronic prescribing.* Int J Med Inform, 2010. **79**(7): p. 507-14.

137. Westbrook, J.I., Baysari, M.T., Li, L.,et al., *The safety of electronic prescribing: manifestations, mechanisms, and rates of system-related errors associated with two commercial systems in hospitals.* J Am Med Inform Assoc, 2013. **20**(6): p. 1159-67.

138. Odukoya, O.K., J.A. Stone, and M.A. Chui, *E-prescribing errors in community pharmacies: exploring consequences and contributing factors.* Int J Med Inform, 2014. **83**(6): p. 427-37.

139. Snyder, A.M., Klinker, K., Orrick, J.J., et al., *An in-depth analysis of medication errors in hospitalized patients with HIV.* Ann Pharmacother, 2011. **45**(4): p. 459-68.

140. Jaderlund Hagstedt, L., C.E. Rudebeck, and G. Petersson, *Usability of computerised physician order entry in primary care: assessing ePrescribing with a new evaluation model.* Inform Prim Care, 2011. **19**(3): p. 161-8.

141. Zhan, C., Hicks, R.W., Blanchette, C.M., et al., *Potential benefits and problems with computerized prescriber order entry: analysis of a voluntary medication error-reporting database.* Am J Health Syst Pharm, 2006. **63**(4): p. 353-8.

142. Odukoya, O.K. and M.A. Chui, *Relationship between E-Prescriptions and Community Pharmacy Workflow.* J Am Pharm Assoc, 2012. **52**(6): p. e168-e174.

143. Wentzer, H.S., U. Bottger, and N. Boye, *Unintended transformations of clinical relations with a computerized physician order entry system.* Int J Med Inform, 2007. **76 Suppl 3**: p. S456-61.

144. Nanji, K.C., Rothsschild, J.M., Boehne, J.J., et al., *Unrealized potential and residual consequences of electronic prescribing on pharmacy workflow in the outpatient pharmacy.* J Am Med Inform Assoc, 2014. **21**(3): p. 481-6.

145. Khajouei, R., Wierenga, p.C., Hasman, A., et al., *Clinicians satisfaction with CPOE ease of use and effect on clinicians' workflow, efficiency and medication safety.* Int J Med Inform, 2011. **80**(5): p. 297-309.

146. Odukoya, O.C., Chui, M. A., *Examining the impact of e-prescribing use on community pharmacy workflow.* J Am Pharm Assoc, 2012. **52 (2)**: p. 262

147. Chan, J. Shojania, K.G., Easty, A.C., et al., *Does user-centred design affect the efficiency, usability and safety of CPOE order sets?* J Am Med Inform Assoc, 2011. **18**(3): p. 276-81.

148. Lambert, B.L., S.R. Schroeder, and W.L. Galanter, *Does Tall Man lettering prevent drug name confusion errors? Incomplete and conflicting evidence suggest need for definitive study.* BMJ Qual Saf, 2016. **25**(4): p. 213-217.

149. Gerrett, D., Gale, A.G., Darker, I.T., et al., *Tall Man Lettering:Final Report of The Use of Tall Man Lettering to Minimise Selection Errors of Medicine Names in Computer Prescribing and Dispensing Systems ITQ Invitation Reference No. : ER-07-0612* NHS Connecting for Health, 2009.

150. Galanter, W., Kalck, S., Burns, M., et al., *Indication-based prescribing prevents wrong-patient medication errors in computerized provider order entry (CPOE).* J Am Med Inform Assoc., 2013. **20**(3): p. 477-481.

151. Slight, S.P., Eguale, T., Amato, M.G., et al., *The vulnerabilities of computerized physician order entry systems: a qualitative study.* J Am Med Inform Assoc, 2016. **23**(2): p. 311-6.
152. Eslami, S., Abu-Hanna, A., de Keizer, N.F., et al., *Errors associated with applying decision support by suggesting default doses for aminoglycosides.* Drug Saf, 2006. **29**(9): p. 803-9.
153. Bobb, A.M., T.H. Payne, and P.A. Gross, *Viewpoint: Controversies Surrounding Use of Order Sets for Clinical Decision Support in Computerized Provider Order Entry.* J Am Med Inform Assoc. 2007. **14**(1): p. 41-47.
154. Palchuk, M.B., Fang, E.A., Cygielnik, J.M., et al., *An unintended consequence of electronic prescriptions: prevalence and impact of internal discrepancies.* J Am Med Inform Assoc. 2010. **17**(4): p. 472-476.
155. Dhavle, A.A., Yang, Y., Rupp, M.T., et al., *Analysis of Prescribers' Notes in Electronic Prescriptions in Ambulatory Practice.* JAMA Intern Med, 2016. **176**(4): p. 463-70.
156. Walsh, K.E., Adams, W.G., Bauchner, H., et al., *Medication errors related to computerized order entry for children.* Pediatrics, 2006. **118**(5): p. 1872-9.
157. Cresswell, K.M., D.W. Bates, and A. Sheikh, *Ten key considerations for the successful optimization of large-scale health information technology.* J Am Med Inform Assoc, 2017. **24**(1): p. 182-187.
158. Wright, A., Hickman, T.T., McEvoy, D., et al., *Analysis of clinical decision support system malfunctions: a case series and survey.* J Am Med Inform Assoc, 2016. **23**(6): p. 1068-1076.
159. Leung, A.A., Keohane, C., Lipsitz, S., et al., *Relationship between medication event rates and the Leapfrog computerized physician order entry evaluation tool.* J Am Med Inform Assoc, 2013. **20**(e1): p. e85-90.
160. Jaspers, M.W., *A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence.* Int J Med Inform, 2009. **78**(5): p. 340-53.
161. Velez-Diaz-Pallares, M., Delgado-Silveira, E., Carretero-Accame, M.E., et al., *Using Healthcare Failure Mode and Effect Analysis to reduce medication errors in the process of drug prescription, validation and dispensing in hospitalised patients.* BMJ Qual Saf, 2013. **22**(1): p. 42-52.
162. Friedman, M., Wyatt, J, *Evaluation Methods in Biomedical Informatics (Health Informtics)* Second Edition, 2005: Springer.
163. Russ, A.L., Zillich, A.J., Melton, B.L., et al., *Applying human factors principles to alert design increases efficiency and reduces prescribing errors in a scenario-based simulation.* J Am Med Inform Assoc, 2014. **21**(e2): p. e287-96.
164. National Institute for Clinical Excellence, *Medicines optimisation: the safe and effective use of medicines to enable the best possible outcomes*. 2015.
165. Tolley, C.L., Forde, N.E., Coffey, K.L., et al., *Factors contributing to medication errors made when using computerized order entry in pediatrics: a systematic review.* J Am Med Inform Assoc, 2018. 25(5):575-584.
166. Smith, M.D., Spiller, H.A., Casavant, M.J., et al., *Out-of-Hospital Medication Errors Among Young Children in the United States, 2002–2012.* Pediatrics, 2014.
167. Miller, M.R., Robinson, K.A., Lubomski, L.H., et al., *Medication errors in paediatric care: a systematic review of epidemiology and an evaluation of evidence supporting reduction strategy recommendations.* Qual Saf Health Care, 2007. **16**(2): p. 116-126.
168. Kaushal, R., Bates, D.W., Landrigan, C., et al., *MEdication errors and adverse drug events in pediatric inpatients.* JAMA, 2001. **285**(16): p. 2114-2120.
169. Hughes, R.G. and E.A. Edgerton, *Reducing pediatric medication errors: children are especially at risk for medication errors.* Am J Nurs, 2005. **105**(5): p. 79-80.

170. Gerstle, R.S. and C.U. Lehmann, *Electronic Prescribing Systems in Pediatrics: The Rationale and Functionality Requirements.* Pediatrics, 2007. **119**(6): p. e1413-e1422.

171. Chedoe, I., Molendijk, H.A., Dittrich, S.T.A., et al., *Incidence and Nature of Medication Errors in Neonatal Intensive Care with Strategies to Improve Safety.* Drug Saf, 2007. **30**(6): p. 503-513.

172. King, W.J., Paice, N., Rangrej, J., et al., *The effect of computerized physician order entry on medication errors and adverse drug events in pediatric inpatients.* Pediatrics, 2003. **112**(3 Pt 1): p. 506-9.

173. Reckmann, M.H., Westbrook, J.I., Koh, Y., et al., *Does computerized provider order entry reduce prescribing errors for hospital inpatients? A systematic review.* J Am Med Inform Assoc, 2009. **16**.

174. Ghaleb, M.A., Barber, N., Dean Franklin, B., et al., *Systematic Review of Medication Errors in Pediatric Patients.* Ann Pharmacother, 2006. **40**(10): p. 1766-1776.

175. Ferranti, J.M., Horvath, M.M., Jeanette., J., et al., *Using a computerized provider order entry system to meet the unique prescribing needs of children: description of an advanced dosing model.* BMC Med Inform Decis Mak, 2011. **11**(1): p. 14.

176. Johnson, K.B. and C.U. Lehmann, *Electronic Prescribing in Pediatrics: Toward Safer and More Effective Medication Management.* Pediatrics, 2013. **131**(4): p. e1350-e1356.

177. Thomas, D.R., *A General Inductive Approach for Analyzing Qualitative Evaluation Data.* Am. J. Eval, 2006. **27**(2): p. 237-246.

178. Creswell, J.W. and D.L. Miller, *Determining Validity in Qualitative Inquiry.* Theory Pract, 2000. **39**(3): p. 124-130.

179. Doherty, C. and C. Mc Donnell, *Tenfold Medication Errors: 5 Years' Experience at a University-Affiliated Pediatric Hospital.* Pediatrics, 2012. **129**(5): p. 916-924.

180. Holdsworth, M.T., Fichtl, R.E., Raisch, D.W., et al., *Impact of computerized prescriber order entry on the incidence of adverse drug events in pediatric inpatients.* Pediatrics, 2007. **120**(5): p. 1058-66.

181. Walsh, K.E., Landrigan, C. P., Adams, W.G., et al., *Effect of computer order entry on prevention of serious medication errors in hospitalized children.* Pediatrics, 2008. **121**.

182. Doherty, C. and C. McDonnell, *Tenfold medication errors in pediatric hospital practiceCan J Anaesth*, 2011. **58**: p. S168.

183. Kazemi, A., Ellenius, J., Pourasghar, F., et al., *The Effect of Computerized Physician Order Entry and Decision Support System on Medication Errors in the Neonatal Ward: Experiences from an Iranian Teaching Hospital.* J Med Syst 2011. **35**(1): p. 25-37.

184. Stultz, J.S., K. Porter, and M.C. Nahata, *Sensitivity and specificity of dosing alerts for dosing errors among hospitalized pediatric patients.* J Am Med Inform Assoc, 2014. **21**(e2): p. e219-25.

185. McPhillips, H.A., Stille, C.J., Smith, D., et al., *Potential Medication Dosing Errors in Outpatient Pediatrics.* The Journal of Pediatrics, 2005. **147**(6): p. 761-767.

186. Jani, Y.H., N. Barber, and I.C.K. Wong, *Paediatric dosing errors before and after electronic prescribing.* Qual Saf Health Care, 2010. **19**(4): p. 337-340.

187. Scharnweber, C., Lau, B.D., Mollenkopf, N., et al., *Evaluation of medication dose alerts in pediatric inpatients.* Int J Med Inform, 2013. **82**(8): p. 676-83.

188. Kirk, R.C., Goh, D.L-M., Packia, J., et al., *Computer Calculated Dose in Paediatric Prescribing.* Drug Saf, 2005. **28**(9): p. 817-824.

189. Jani, Y.H., Ghaleb, M.A., Marks, S.D., et al., *Electronic Prescribing Reduced Prescribing Errors in a Pediatric Renal Outpatient Clinic.* J Pediatr, 2008. **152**(2): p. 214-218.

190. Summary of Product Characteristics: *Ceftriaxone 1g Powder for solution for injection*. 2015; Available from: https://www.medicines.org.uk/emc/medicine/5469 [last accessed 14th May 2017].

191. Caruso, M.C., Gittelman, M.A., Widecan, M.L., et al., *Pediatric emergency department discharge prescriptions requiring pharmacy clarification.* Pediatr Emerg Care, 2015. **31**(6): p. 403-8.

192. Condren, M., Honey, B.L., Carter, S.M., et al., *Influence of a systems-based approach to prescribing errors in a pediatric resident clinic.* Acad Pediatr, 2014. **14**(5): p. 485-90.

193. Cochran, G.L., Klepser, D.G., Morien, M., et al., *From physician intent to the pharmacy label: prevalence and description of discrepancies from a cross-sectional evaluation of electronic prescriptions.* BMJ Qual Saf, 2014. **23**(3): p. 223-230.

194. Warrick, C., Naik, H., Avis., et al., *A clinical information system reduces medication errors in paediatric intensive care.* Intensive Care Med, 2011. **37**(4): p. 691-4.

195. Nelson, C.E. and S.M. Selbst, *Electronic prescription writing errors in the pediatric emergency department.* Pediatr Emerg Care, 2015. **31**(5): p. 368-72.

196. Kim, G.R., Chen, A.R., Arceci, R.J., et al., *Error reduction in pediatric chemotherapy: Computerized order entry and failure modes and effects analysis.* Arch Pediatr Adolesc Med, 2006. **160**(5): p. 495-498.

197. Stultz, J.S. and M.C. Nahata, *Appropriateness of commercially available and partially customized medication dosing alerts among pediatric patients.* J Am Med Inform Assoc, 2014. **21**(e1): p. e35-42.

198. Sethuraman, U., Kannikeswaran, N., Murray, K.P., et al., *Prescription errors before and after introduction of electronic medication alert system in a pediatric emergency department.* Acad Emerg Med, 2015. **22**(6): p. 714-9.

199. Kadmon, G., Bron-Harlev, E., Nahum, E., et al., *Computerized order entry with limited decision support to prevent prescription errors in a PICU.* Pediatrics, 2009. **124**(3): p. 935-40.

200. Apkon, M., Leonard, J., Probst, L., et al., *Design of a safer approach to intravenous drug infusions: failure mode effects analysis.* Qual Saf Health Care, 2004. **13**(4): p. 265-271.

201. Potts, A.L., Barr, F.E., Gregory, D.F., et al., *Computerized Physician Order Entry and Medication Errors in a Pediatric Critical Care Unit.* Pediatrics, 2004. **113**(1): p. 59-63.

202. Kaestli, L.Z., Cingria, L., Fonzo-Christe, C., et al., *Prospective risk analysis and incident reporting for better pharmaceutical care at paediatric hospital discharge.* Int J Clin Pharm, 2014. **36**(5): p. 953-62.

203. Tora, H., Bo, H., Bodil, L., et al., *Potential drug related problems detected by electronic expert support system in patients with multi-dose drug dispensing.* Int J Clin Pharm, 2014. **36**(5): p. 943-52.

204. van Tilburg, C.M., Leistikow, I.P., Rademaker, C.M.A., et al., *Health care failure mode and effect analysis: a useful proactive risk analysis in a pediatric oncology ward.* Qual Saf Health Care, 2006. **15**(1): p. 58-63.

205. Pacheco, G.S., Viscusi, C., Hays, D.P., et al., *The Effects of Resident Level of Training on the Rate of Pediatric Prescription Errors in an Academic Emergency Department.* J Emerg Med. **43**(5): p. e343-e348.

206. Patterson, E.S., Zhang, J., Abbott, P., et al., *Enhancing electronic health record usability in pediatric patient care: a scenario-based approach.* Jt Comm J Qual Patient Saf, 2013. **39**(3): p. 129-35.

207. Wald, J.S., Webb, J.R., Haque, S., *Children's EHR Format Enhancement: Final Recommendation Report. (Prepared by RTI International under Contract No. HHSA*

290-2009-00021I). AHRQ Publication No.15-0077-EF, Agency for Healthcare Research and Quality Rockville, November 2015.

208. Kazemi, A., Fors, U.G., Tofighi, S., et al., *Physician order entry or nurse order entry? Comparison of two implementation strategies for a computerized order entry system aimed at reducing dosing medication errors.* J Med Internet Res, 2010. **12**(1): p. e5.

209. Manrique-Rodríguez, S., et al., *Smart pump alerts: All that glitters is not gold.* International Journal of Medical Informatics, 2012. **81**(5): p. 344-350.

210. Hou, J.-Y., Cheng, K-J., Bai, K-J., et al., *The effect of a computerized pediatric dosing decision support system on pediatric dosing errors.* J Food Drug Anal, 2013. **21**(3): p. 286-291.

211. Lehmann, C.U., *Pediatric Aspects of Inpatient Health Information Technology Systems.* Pediatrics, 2015. **135**(3): p. e756-e768.

212. Jani, Y.H., N. Barber, and I.C. Wong, *Republished error management: Paediatric dosing errors before and after electronic prescribing.* Postgrad Med J, 2011. **87**(1030): p. 565-8.

213. Ekedahl, A., *Problem prescriptions in Sweden necessitating contact with the prescriber before dispensing.* Res Social Adm Pharm, 2010. **6**(3): p. 174-84.

214. Walsh, K.E., Landrigan, C.P., Adams, W.G., et al., *Effect of Computer Order Entry on Prevention of Serious Medication Errors in Hospitalized Children.* Pediatrics, 2008. **121**(3): p. e421-e427.

215. Khajouei, R. and M.W. Jaspers, *CPOE system design aspects and their qualitative effect on usability.* Stud Health Technol Inform, 2008. **136**: p. 309-14.

216. Schiff, G.D., E. Seoane-Vazquez, and A. Wright, *Incorporating Indications into Medication Ordering--Time to Enter the Age of Reason.* N Engl J Med, 2016. **375**(4): p. 306-9.

217. Lowry, S.Z., Quinn, M.T., Ramaiah, M., *A Human Factors Guide to Enhance EHR Usability of Critical User Interactions when Supporting Pediatric Patient Care*, National Institute of Standards and Technology, 2012.

218. Sard, B.E., Walsh, K.E., Doros, G., et al., *Retrospective evaluation of a computerized physician order entry adaptation to prevent prescribing errors in a pediatric emergency department.* Pediatrics, 2008. **122**(4): p. 782-7.

219. Maat, B., Au, Y.S., Bollen, C.W., et al., *Clinical pharmacy interventions in paediatric electronic prescriptions.* Arch Dis Child, 2013. **98**(3): p. 222-7.

220. Ginzburg, R., Barr, W.B., Harris, M., et al., *Effect of a weight-based prescribing method within an electronic health record on prescribing errors.* Am J Health Syst Pharm, 2009. **66**(22): p. 2037-41.

221. Han, Y.Y., Carcillo, J.A., Venkataraman, S.T., et al., *Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system.* Pediatrics, 2005. **116**(6): p. 1506-12.

222. Abboud, P.A., Ancheta, R., McKibben, M., et al., *Impact of workflow-integrated corollary orders on aminoglycoside monitoring in children.* Health Informatics J, 2006. **12**(3): p. 187-98.

223. Russell, R.A., Triscari, D., Murkowski, K., et al., *Impact of Computerized Order Entry to Pharmacy Interface on Order-Infusion Pump Discrepancies.* J Drug Deliv, 2015. **2015**: p. 6. 686598

224. Webber, E.C., Warhurst, H.M., Smith, S.S., et al., *Conversion of a Single-Facility Pediatric Antimicrobial Stewardship Program to Multi-Facility Application with Computerized Provider Order Entry and Clinical Decision Support.* Appl Clin Inform, 2013. **4**(4): p. 556-568.

225. Russell, R.A., K. Murkowski, and M.C. Scanlon, *Discrepancies between medication orders and infusion pump programming in a paediatric intensive care unit.* Qual Saf Health Care, 2010. **19 Suppl 3**: p. i31-5.

226. Taylor, J.A., Loan, L.A., Kamara, J., et al., *Medication administration variances before and after implementation of computerized physician order entry in a neonatal intensive care unit.* Pediatrics, 2008. **121**(1): p. 123-8.

227. Gattari, T.B., Krieger, L.N., Hu, H.M., et al., *Medication Discrepancies at Pediatric Hospital Discharge.* Hosp Pediatr, 2015. **5**(8): p. 439-45.

228. Lehmann, C.U. and G.R. Kim, *Computerized provider order entry and patient safety.* Pediatr Clin North Am, 2006. **53**(6): p. 1169-84.

229. Vaidya, V., Sowan, A.K., Mills, M.E., et al., *Evaluating the safety and efficiency of a CPOE system for continuous medication infusions in a pediatric ICU.* AMIA Annu Symp Proc, 2006: p. 1128.

230. Cordero, L., Kuehn, L., Kumar, R.R., et al., *Impact of computerized physician order entry on clinical practice in a newborn intensive care unit.* J Perinatol, 2004. **24**(2): p. 88-93.

231. Dean Franklin, B., O'Grady, K., Donyai, P., et al., *The impact of a closed-loop electronic prescribing and administration system on prescribing errors, administration errors and staff time: a before-and-after study.* Qual Saf Health Care, 2007. **16**(4): p. 279-284.

232. Alhanout, K., Bun, S-S, Retornaz, K., et al., *Prescription errors related to the use of computerized provider order-entry system for pediatric patients.* Int J Med Inform, 2017. **103**: p. 15-19.

233. Lee, F., Teich, J.M., Spurr, C.D., et al., *Implementation of physician order entry: user satisfaction and self-reported usage patterns.* J Am Med Inform Assoc, 1996. **3**(1): p. 42-55.

234. Niazkhani, Z., Pirnejad, H., Berg, M., et al., *The Impact of Computerized Provider Order Entry Systems on Inpatient Clinical Workflow: A Literature Review.* J Am Med Inform Assoc, 2009. **16**(4): p. 539-549.

235. Rinke, M.L., Bundy, D.G., Velasquez, C.A., et al., *Interventions to Reduce Pediatric Medication Errors: A Systematic Review.* Pediatrics, 2014.

236. Ash, J.S., M. Berg, and E. Coiera, *Some Unintended Consequences of Information Technology in Health Care: The Nature of Patient Care Information System-related Errors.* J Am Med Inform Assoc, 2004. **11**(2): p. 104-112.

237. Her, Q.L., Amato, M.G., Seger, D.L., et al., *The frequency of inappropriate nonformulary medication alert overrides in the inpatient setting.* J Am Med Inform Assoc, 2016. **23**(5): p. 924-33.

238. Ruiz, J.G., M.J. Mintzer, and R.M. Leipzig, *The impact of E-learning in medical education.* Acad Med, 2006. **81**(3): p. 207-12.

239. Noblin, A., Cortelyou-Ward, K., Cantiello, J., et al., *EHR implementation in a new clinic: a case study of clinician perceptions.* J Med Syst, 2013. **37**(4): p. 9955.

240. Jimenez, A., *E-learning supports EHR implementations. In addition to meaningful use, we need to define meaningful training.* Health Manag Technol, 2010. **31**(11): p. 22-3.

241. Borycki, E.M., Kushniruk, A.W., Joe, R., et al., *The University of Victoria Interdisciplinary Electronic Health Record Educational Portal.* Stud Health Technol Inform, 2009. **143**: p. 49-54.

242. Bredfeldt, C.E., Awad, E.B., Joseph, K., et al., *Training providers: beyond the basics of electronic health records.* BMC Health Serv Res, 2013. **13**: p. 503.

243. Kushniruk, A.W., Borycki, E.M., Armstrong, B., et al., *Bringing electronic patient records into health professional education: towards an integrative framework.* Stud Health Technol Inform, 2009. **150**: p. 883-7.

244. Foster, S., Murray, D., Richardson, J., et al., *Competency based training program for electronic prescribing improves patient safety.* Pediatr Crit Care, 2011. **1)**: p. A19.

245. Ayoub, N., Sheikh, A.L., Ahsan, S., et al., *Developing competency through webinar to establish oncology pharmacy services at the Aga Khan Hospital Dar-es-Salaam Tanzania.* J Oncol Pharm Pract, 2014. **1)**: p. 10.

246. Borycki, E.M., B. Armstrong, and A.W. Kushniruk, *From Prototype to Production: Lessons Learned from the Evolution of an EHR Educational Portal.* AMIA Annu Symp Proc, 2009. **2009**: p. 55-59.

247. Borycki, E.M., B. Armstrong, and A.W. Kushniruk, *From prototype to production: lessons learned from the evolution of an EHR educational portal.* AMIA Annu Symp Proc, 2009. **2009**: p. 55-9.

248. Ross, C. and P. Banchy, *The key to CPOE: thoughtful planning, flexible training and strong staff involvement leads to a successful CPOE implementation.* Health Manag Technol, 2007. **28**(11): p. 22-24.

249. American Health Information Management Association, *Building the Work Force for Health Information Transformation*, American Medical Informatics Association, 2006.

250. McCain, C.L., *The Right Mix to Support Electronic Medical Record Training: Classroom Computer-Based Training and Blended Learning.* Journal for Nurses in Professional Development, 2008. **24**(4): p. 151-154.

251. Edwards, G., R.R. Kitzmiller, and S. Breckenridge-Sproat, *Innovative health information technology training: exploring blended learning.* Comput Inform Nurs, 2012. **30**(2): p. 104-9.

252. Laramee, A.S., Bosek, M., Kasprisin, C.A., et al., *Learning from within to ensure a successful implementation of an electronic health record.* Comput Inform Nurs, 2011. **29**(8): p. 468-77.

253. Topaz, M., Rao, A., Masterson Creber, R. et al., *Educating clinicians on new elements incorporated into the electronic health record: theories, evidence, and one educational project.* Comput Inform Nurs, 2013. **31**(8): p. 375-9.

254. Halamka, J., Aranow, M., Ascenzo, C., et al., *E-Prescribing Collaboration in Massachusetts: Early Experiences from Regional Prescribing Projects.* J Am Med Inform Assoc, 2006. **13**(3): p. 239-244.

255. Ash, J.S. and D.W. Bates, *Factors and forces affecting EHR system adoption: report of a 2004 ACMI discussion.* J Am Med Inform Assoc, 2005. **12**(1): p. 8-12.

256. Campbell, E.M., Sittig, D.F., Guappone, K.P., et al., *Overdependence on Technology: An Unintended Adverse Consequence of Computerized Provider Order Entry.* AMIA Annu Symp Proc, 2007. **2007**: p. 94-98.

257. Sittig, D.F., Ash, J.S., Guappone, K.P., et al., *Assessing the Anticipated Consequences of Computer-based Provider Order Entry at Three Community Hospitals Using an Open-ended, Semi-structured Survey Instrument.* Int J Med Inform, 2008. **77**(7): p. 440-447.

258. van Stiphout, F., Zwart-van Rijkom, J. E. F., Maggio, L.A., et al., *Task analysis of information technology-mediated medication management in outpatient care.* Br J Clin Pharmacol, 2015. **80**(3): p. 415-424.

259. Biggs, J., *Aligning teaching for constructing learning*, The HIgher Education Academy, 2003. p. p1-4.

260. Pope, C. and N. Mays, *Reaching the parts other methods cannot reach: an introduction to qualitative methods in health and health services research.* BMJ, 1995. **311**(6996): p. 42-45.

261. *Ritchie, J. & Spencer, L. 1994. Qualitative data analysis for applied policy research by Jane Ritchie and Liz Spencer in A. Bryman and R. G. Burgess, 'Analysing qualitative data', (pp.173-194). London: Routledge*.

262. Walker, D. and F. Myrick, *Grounded theory: An exploration of process and procedure.* Qual Health Res. 2006. **16**(4): p. 547-559.

263. Glaser, B.G. and A.L. Strauss, *The discovery of grounded theory : strategies for qualitative research*. Observations. 1967, Chicago.

264. Gale, N., Health, G., Cameron, E., et al., *Using the framework method for the analysis of qualitative data in multi-disciplinary health research.* BMC Med Res Methodol. 2013. **13**(1): p. 117.

265. Harrison, H., Birks, M., Richard, F., et al., *Case Study Research: Foundations and Methodological Orientations.* 2017. **18**(1).

266. Creswell, J.W., *Research design : qualitative, quantitative, and mixed methods approaches*. Fourth edition, International student edition. 2014, Thousand Oaks, CA;London: Sage Publications.

267. Barbour, R.S., *Introducing qualitative research : a student's guide*. 2nd ed. 2014, London: SAGE.

268. Pope, C., P. van Royen, and R. Baker, *Qualitative methods in research on healthcare quality.* Qual Saf Health Care, 2002. **11**(2): p. 148-152.

269. Cunningham, C.T., Quan, H., Hemmelgarn, B., et al., *Exploring physician specialist response rates to web-based surveys.* BMC Med Res Methodol. 2015. **15**: p. 32.

270. Lyratzopoulos, G., Elliott, M., Barbiere, J.M., et al., *Understanding ethnic and other socio-demographic differences in patient experience of primary care: evidence from the English General Practice Patient Survey.* BMJ Qual Saf, 2012. **21**(1): p. 21-29.

271. Cohen D, C.B. *Qualitative Research Guidelines Project*. 2006 [cited 2014; Available from: http://www.qualres.org/HomeUnst-3630.html.

272. Cohen D, C.B. *Qualitative Research Guidelines Project*. 2006 [cited 2014 26.11.14]; Available from: http://www.qualres.org/HomeObse-3594.html.

273. Glaser, B.G. and A.L. Strauss, *The discovery of grounded theory: Strategies for qualitative research*. 2009: Transaction publishers.

274. Mays, N. and C. Pope, *Qualitative research in health care. Assessing quality in qualitative research.* BMJ, 2000. **320**(7226): p. 50-2.

275. Smith, J.A., *Qualitative psychology : a practical guide to research methods*. 2003, London: SAGE Publications.

276. Ritchie, J., *Qualitative research practice : a guide for social science students and researchers*. 2nd ed.

277. Creswell, J.W., *Qualitative inquiry and research design : choosing among five approaches*. 2nd ed. 2007, Thousand Oaks, CA: SAGE.

278. Pope, C., S. Ziebland, and N. Mays, *Analysing qualitative data.* BMJ, 2000. **320**: p. 114 - 116.

279. Miles, M.B. and A.M. Huberman, *The qualitative researcher's companion*. 2002, Thousand Oaks, CA: Sage Publications.

280. Finlay, L., *Negotiating the swamp: the opportunity and challenge of reflexivity in research practice.* Qualitative Research, 2002. **2**(2): p. 209-230.

281. Clinical Applications and Patient Safety Project NHS CUI Programme Team, *Displaying Graphs and Tables User Interface Design Guidance*, Health and Social Care Information Centre, 2015.

282. Julia Adler-Milstein, *Moving Past the EHR Interoperability Blame Game.* NEJM Catalyst, 2017.

283. Westbrook, J.I., Reckmann, M., Li, L., et al., *Effects of Two Commercial Electronic Prescribing Systems on Prescribing Error Rates in Hospital In-Patients: A Before and After Study.* PLoS Med, 2012. **9**(1): p. e1001164.

284. Middleton, B., Bloomrosen, M., Dente, M.A., et al., *Enhancing patient safety and quality of care by improving the usability of electronic health record systems: recommendations from AMIA.* J Am Med Inform Assoc, 2013. **20**(e1): p. e2-e8.

285. Salman, Y.B., Kim, J.Y., Karahoca, A., et al., *Participatory icon design for medical information systems.* Hong Kong: International Association of Design Research, 2007.

286. Howe, J.L., Adams, K.T., Hettinger, A., et al., *Electronic health record usability issues and potential contribution to patient harm.* JAMA, 2018. **319**(12): p. 1276-1278.

287. Wright, A., Feblowitz, J.C., Pang, J.E., et al., *Use of Order Sets in Inpatient Computerized Provider Order Entry Systems: A Comparative Analysis of Usage Patterns at Seven Sites.* Int J Med Inform, 2012. **81**(11): p. 733-745.

288. Puaar, S.J. and B.D. Franklin, *Impact of an inpatient electronic prescribing system on prescribing error causation: a qualitative evaluation in an English hospital.* BMJ Qual Saf, 2017.

289. Galanter, W.L., Bryson, M.L., Falck, S., et al., *Indication Alerts Intercept Drug Name Confusion Errors during Computerized Entry of Medication Orders.* PLOS ONE, 2014. **9**(7): p. e101977.

290. Singh, H., Mani, S., Espadas, D., et al., *Prescription errors and outcomes related to inconsistent information transmitted through computerized order entry: a prospective study.* Arch Intern Med, 2009. **169**(10): p. 982-9.

291. Zheng, K., Hanauer, D.A., Padman, R., et al., *Handling anticipated exceptions in clinical care: investigating clinician use of 'exit strategies' in an electronic health records system.* J Am Med Inform Assoc, 2011. **18**(6): p. 883-889.

292. Sittig , D.F. and H. Singh *Electronic Health Records and National Patient-Safety Goals.* NEJM, 2012. **367**(19): p. 1854-1860.

293. Amato, M.G., Salazar, A., Hickman, T-T.T., et al., *Computerized prescriber order entry–related patient safety reports: analysis of 2522 medication errors.* J Am Med Inform Assoc, 2017. **24**(2): p. 316-322.

294. Magrabi, F., Ong, M-S., Runciman, W., et al., *Using FDA reports to inform a classification for health information technology safety problems.* J Am Med Inform Assoc, 2012. **19**(1): p. 45-53.

295. Wright, A., Ai, Angela., Ash, J., et al., *Clinical decision support alert malfunctions: analysis and empirically derived taxonomy.* J Am Med Inform Assoc, 2018. **25**(5): p. 496-506.

296. Giuliano, C.A., Binienda, J., Kale-Pradhan, P.B., et al., *"I Never Would Have Caught That Before": Pharmacist Perceptions of Using Clinical Decision Support for Antimicrobial Stewardship in the United States.* Qual Health Research. 2018 **28**(5):745-755.

297. Allen, J., Bush, J., Timmins, J., et al., *667: Impact of a multimodal antibiotic stewardship program in the ICU results from a 16-hospital system.* Crit Care Med, 2018. **46**(1): p. 320.

298. Di Pentima, M.C., S. Chan, and J. Hossain, *Benefits of a Pediatric Antimicrobial Stewardship Program at a Children's Hospital.* Pediatrics, 2011. **128**(6): p. 1062-1070.

215

299. Blijleven, V., Koelemeijer, K., Wetzels, M., et al., *Workarounds Emerging From Electronic Health Record System Usage: Consequences for Patient Safety, Effectiveness of Care, and Efficiency of Care.* JMIR Hum Factors, 2017. **4**(4): p. e27.

300. McAlister, F.A. and K.G. Shojania, *Inpatient bedspacing: could a common response to hospital crowding cause increased patient mortality?* BMJ Qual Saf 2018. **27**(1): p. 1-3.

301. Campbell, R.J., *The five rights of clinical decision support: CDS tools helpful for meeting meaningful use.* Journal of AHIMA, 2013. **84**(10): p. 42-47 (web version updated February 2016).

302. Osheroff, J.A. *Improving outcomes with clinical decision support: an implementer's guide*. 2012. Health Information and Management Systems Society.

303. Baysari, M.T., Westbrook, J.I., Richardson, K.L., et al., *The influence of computerized decision support on prescribing during ward-rounds: are the decision-makers targeted?* J Am Med Inform Assoc, 2011. **18**(6): p. 754-759.

304. Riedmann, D., Jung, M., Hackl, W.O., et al., *How to improve the delivery of medication alerts within computerized physician order entry systems: an international Delphi study.* J Am Med Inform Assoc, 2011. **18**(6): p. 760-766.

305. Grizzle, A.J., Mahmood, M.H., Ko, Y., et al., *Reasons provided by prescribers when overriding drug-drug interaction alerts.* Am J Manag Care, 2007. **13**(10): p. 573-8.

306. Czock, D., Konias, M., Seidling, H.M., et al., *Tailoring of alerts substantially reduces the alert burden in computerized clinical decision support for drugs that should be avoided in patients with renal disease.* J Am Med Inform Assoc, 2015. **22**(4): p. 881-887.

307. Cornu, P., Steurbaut, S., Gentens, K., et al., *Pilot evaluation of an optimized context-specific drug–drug interaction alerting system: A controlled pre-post study.* Int J Med Inform, 2015. **84**(9): p. 617-629.

308. Seidling, H.M., Schmitt, S.P., Bruckner, T., et al., *Patient-specific electronic decision support reduces prescription of excessive doses.* Qual Saf Health Care, 2010. **19**.

309. Bates, D.W., Kuperman, G.J., Wang, S., et al., *Ten Commandments for Effective Clinical Decision Support: Making the Practice of Evidence-based Medicine a Reality.* J Am Med Inform Assoc, 2003. **10**(6): p. 523-530.

310. Hayward, J., Thomson, F., Milne, H., et al., *'Too much, too late': mixed methods multi-channel video recording study of computerized decision support systems and GP prescribing.* J Am Med Inform Assoc, 2013. **20**(e1): p. e76-e84.

311. Horsky, J., Schiff, G.D., Johnston, D., et al., *Interface design principles for usable decision support: A targeted review of best practices for clinical prescribing interventions.* J Biomed Inform, 2012. **45**(6): p. 1202-1216.

312. Wright, A., Sittig, D.F., Ash, J.S., et al., *Clinical decision support capabilities of commercially-available clinical information systems.* J Am Med Inform Assoc, 2009. **16**(5): p. 637-44.

313. Genes, N., Kim, M.S., Thum, F.L., et al., *Usability Evaluation of a Clinical Decision Support System for Geriatric ED Pain Treatment.* Appl Clin Inform, 2016. **7**(1): p. 128-42.

314. Hanna, K., Ahonen, R., Pekka, M., et al., *Medication safety and the usability of electronic prescribing as perceived by physicians—A semistructured interview among primary health care physicians in Finland.* J Eval Clin Pract, 2017. **23**(6): p. 1187-1194.

315. Sopan, A., Plaisant, C., Powsner, S., et al., *Reducing wrong patient selection errors: exploring the design space of user interface techniques.* AMIA Annu Symp Proc, 2014. **2014**: p. 1056-65.

316. Zhang, J., Johnson, T.R., Patel, V.L., et al., *Using usability heuristics to evaluate patient safety of medical devices.* J Biomed Inform, 2003. **36**(1): p. 23-30.

317.   Horsky, J., Phansalkar, S., Desai, A., et al., *Design of decision support interventions for medication prescribing.* Int J Med Inform, 2013. **82**(6): p. 492-503.

318.   Helander, M., Landauer, T.K., and Prabhu, P.V., *Handbook of human-computer interaction.* 2nd ed. 1997, Elsevier.

319.   Falconer, N., Liow, D., Zeng, I., et al., *Validation of the assessment of risk tool: patient prioritisation technology for clinical pharmacist interventions.* Eur J Hosp Pharm, 2017, http://dx.doi.org/10.1136/ejhpharm-2016-001165

320.   Hickson, R.P., Steinke, D.T., Skitterall, C., et al., *Evaluation of a pharmaceutical assessment screening tool to measure patient acuity and prioritise pharmaceutical care in a UK hospital.* Eur J Hosp Pharm, 2016. http://dx.doi.org/10.1136/ejhpharm-2015-000829

321.   Vuk, J., Anders, M.E., Mercado, C.C., et al., *Impact of simulation training on self-efficacy of outpatient health care providers to use electronic health records.* Int J Med Inform, 2015. **84**(6): p. 423-429.

322.   Arnold, T. and Fuller, H.J.A., *Generic Customizable Simulation Modules to Emphasize Error Risk in Medication Order Entry.* Proc Int Symp Hum Factors Ergon Healthc, 2016. **5**(1): p. 150-153.

323.   Byers, J.F. and S.V. White, *Patient safety:principles and practice*. 2004, New York, Springer.

324.   Pantaleoni, J.L., Stevens, L.A., Mailes, E.S., et al., *Successful Physician Training Program for Large Scale EMR Implementation.* Appl Clin Inform, 2015. **6**(1): p. 80-95.

325.   Stevens, L.A., Pantaleoni, J.L. and Longhurst, C.A., *The value of clinical teachers for EMR implementations and conversions.* Appl Clin Inform, 2015. **6**(1): p. 75-9.

326.   Goveia, J., van Stiphout, F., Cheung, Z., et al., *Educational interventions to improve the meaningful use of Electronic Health Records: a review of the literature: BEME Guide No. 29.* Med Teach, 2013. **35**(11): p. e1551-60.

327.   Childs, S., Blenkinsopp, E., Hall., Amanda., et al., *Effective e-learning for health professionals and students—barriers and their solutions. A systematic review of the literature—findings from the HeXL project.* Health Info Libr J, 2005. **22**: p. 20-32.

328.   Dixon BE, Zafar A., *Inpatient Computerized Provider Order Entry: Findings from the AHRQ Health IT Portfolio (Prepared by the AHRQ National Resource Center for Health IT)*, AHRQ National Resource Center for Health Information Technology, 2009.

329.   Yuan, C.T., E.H. Bradley, and I.M. Nembhard, *A mixed methods study of how clinician 'super users' influence others during the implementation of electronic health records.* BMC Med Inform and Dec Mak, 2015. **15**: p. 26

Appendix 1: Improving medication-related clinical decision support

Improving medication-related clinical decision support

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Purpose. Current uses of medication-related clinical decision support (CDS) and recommendations for Improving these systems are reviewed.

Summary. Using a systematic approach. articles published from 2007 through 2014 were identified in MEDLINE and EMBASE using MeSH terms and Keywords relating to the 5 basic medication-related CDS functionalities. A total of 156 full-text articles and 28 conference abstracts were re- viewed across each of the 5 areas: drug-drug interaction (DDI) checks (n= 78), drug allergy checks (n=20), drug dose support (n=55), drug- duplication checks (n = 11). and drug formulary support (n = 20). The success of medication-related CDS depends on users finding the alerts valuable and acting on the information received. Improving alert specificity and sensitivity is important for all domains. Tiering is important for improving the acceptance of DDI alerts. The ability to perform appropriate cross- sensitivity checks is key to producing appropriate drug allergy checks. Drug dosage alerts should be individualized and deliver practical recommendations. How the system is configured to identify certain drug duplications is Important to prevent possible patient toxicity. Accurate knowledge databases are needed to produce relevant drug formulary alerts and encourage formulary adherence. Medication-related CDS is still relatively immature in some organizations and has substantial room for improvement For example, decision support should consider more patient-specific factors. Human factors principles should always be considered, and alert specificity must be improved in order to reduce alert fatigue.

Conclusion. Standardization, integration of patient specific parameters and consideration of human factors design principles are central to realizing the potential benefits of medication-related CDS.

Keywords: decision-making. Decision support systems, clinical; electronic prescribing: medical order entry systems: medicat101 errors; patient safety

Appendix 2: Search Strategy for: Improving medication-related clinical decision support (Drug-Drug Interaction search)

1. Clinical decision support
2. Decision Support Systems, Clinical
3. CDS
4. Decision support
5. Decision Making
6. Alert
7. Clinical Alarms
8. Reminders
9. Electronic prescribing
10. EP
11. Computerized provider order entry
12. Computerized physician order entry
13. CPOE
14. Computer assisted
15. Medical order entry
16. Medical Order Entry Systems
17. Electronic Health Records
18. Reminder Systems
19. Medication Systems
20. Drug Interactions
21. Drug drug interaction
22. Drug drug
23. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 (CDS Terms)
24. 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 (EP Terms)
25. 20 or 21 or 22 (Drug-Interaction alert Terms)
26. 23 AND 24 AND 25 (Combination)

Appendix 3: A Systematic Review Of The Types And Causes Of Prescribing Errors Generated From Using Computerized Provider Order Entry Systems in Primary and Secondary Care

OXFORD

Review

A systematic review of the types and causes of prescribing errors generated from using computerized provider order entry systems in primary and secondary care

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ABSTRACT

Objective: To understand the different types and causes of prescribing errors associated with computerized provider order entry (CPOE) systems, and recommend improvements in these systems.

Materials and Methods: We conducted a systematic review of the literature published between January 2004 and June 2015 using three large databases: the Cumulative Index to Nursing and Allied Health Literature, Embase, and Medline. Studies that reported qualitative data about the types and causes of these errors were included. A narrative synthesis of all eligible studies was undertaken.

Results: A total of 1185 publications were identified, of which 34 were included in the review. We identified 8 key themes associated with CPOE-related prescribing errors: computer screen display, drop-down menus and auto- population, wording, default settings, non-intuitive or inflexible ordering, repeat prescriptions and automated processes, users' work processes, and clinical decision support systems. Displaying an incomplete list of a patient's medications on the computer screen often contributed to prescribing errors. Lack of system flexibility resulted in users employing error-prone workarounds, such as the addition of contradictory free-text comments. Users' misinterpretations of how text was presented in CPOE systems were also linked with the occurrence of prescribing errors.

Discussion and Conclusions: Human factors design is important to reduce error rates. Drop-down menus should be designed with safeguards to decrease the likelihood of selection errors. Development of more sophis- ticated clinical decision support, which can perform checks on free-text, may also prevent errors. Further research is needed to ensure that systems minimize error likelihood and meet users' workflow expectations.

Appendix 4: Search strategy for: A Systematic Review Of The Types And Causes Of Prescribing Errors Generated From Using Computerized Provider Order Entry Systems in Primary and Secondary Care as conducted in Medline and Embase via Ovid.

1. Computerized prescriber order entry
2. Computerized provider order entry/
3. Electronic physician order entry
4. Electronic order entry
5. Electronic prescribing/
6. Electronic prescription
7. Computerized physician order entry
8. CPOE
9. Computerized order entry
10. Medical order entry systems
11. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10
12. Clinical decision support
13. Decision support system/
14. CDS
15. Drug therapy, computer assisted
16. 12 or 13 or 14 or 15
17. Electronic medical record/
18. Electronic health record
19. Electronic patient record
20. 17 or 18 or 19
21. Medication Errors
22. Unintended consequences
23. Prescribing error
24. 21 or 22 or 23
25. 11 or 16 or 20
26. 24 AND 25
27. Limit 26 to yr=2004-current
28. Limit 27 to English Language
29. Limit 28 to journal
30. Limit 29 to Qualitative (best balance of sensitivity and specificity) (Medline and Embase Only)

Appendix 5: A table summarising the key findings of the included articles from: a systematic review of the prescribing errors generated from using CPOE in primary and secondary care

Table 1: Summary of Included Studies								Bias Assessment: Methodological Triangulation: Yes/Nno)
Author, Date	**Title**	Aim	Method	Location	Sector	Summary of qualitative findings		
						Types of Error	Causes of Error	
Adelman et al. (2012)	**Understanding and preventing wrong-patient electronic orders: A randomized controlled trial**	Phase 1: To assess the effectiveness of an automated measure of wrong-patient electronic orders. Phase 2: To test the effectiveness of two interventions designed to reduce wrong-patient errors in a three-armed randomized controlled concurrent trial.	Phase 1: Evaluation of a 're-tract and re-order tool'. Semi-structured interviews with providers (n= 223 providers) identified by the tool to determine if a true wrong-patient order had been made; and classification of the cause of error e.g. a juxtaposition error, interruption error or other. Phase 2: Intervention efficacy trial of an identification verify alert and an identification re-entry function	U.S.	Academic Medical Center (Three general hospitals and one children's hospital)	• Wrong patient	• Juxtaposition errors • Interruptions	Yes

Agostini et al. (2007)	Improving sedative-hypnotic prescribing in older hospitalized patients: Provider-perceived benefits and barriers of a computer-based reminder	To explore how clinicians made their prescribing decisions. To determine clinician's attitudes towards a computer-based reminder that has been effective in reducing inappropriate sedative hypnotic drug use, during routine practice.	Semi-structured interviews with house staff physicians from the medical or surgical service (n=36 providers) NB: Reports on the results of one part of a larger piece of work; pre/post evaluation study of a clinical decision support alert also conducted.	U.S.	Hospital (inpatient)	• Inappropriate drug choice	• Demands of reading the reminder • Incorrect alert content	Yes
Ash et al. (2009)	The unintended consequences of CPOE: Findings from a mixed methods exploration	To identify the types of unintended consequences and strategies for preventing, managing or overcoming the unintended consequences of CPOE.	Phase1 study: Observations: (29 hours of observation in four clinics, shadowing 15 clinicians) Interviews: (n=12 clinicians and staff members) Phase 2: Unintended Consequences Study Two expert-panel conferences Observations: (n=390 hours of 95 clinicians) Interviews: (n=32 interviews) Surveys: (n=176 hospital responses)	U.S.	Hospital n=6 (inpatient and outpatient)	• Juxtaposition errors • Inadvertent order entry.	• Pick-lists	Yes

Ash et al. (2007)	**Some unintended consequences of clinical decision support systems**	To analyze and gather data about the unintended consequences of CDS	Observations (n=390 hours of 95 clinicians) Interviews: (n=32 Interviews) Expert panel conference(n=19 experts)	U.S.	Hospital n=5 (inpatient and outpatient)	• Dose Errors • Inappropriate orders • Drug omission	• Lack of CDS • Out of date content • Workarounds • Inflexibility • Alert fatigue • Auto-complete functionality. • Inappropriate timing of alerts.	Yes
Ash et al. (2007)	**The extent and importance of unintended consequences related to computerized provider order entry**	To discover the extent and importance of unintended adverse consequences related to CPOE implementation in U.S. hospitals.	Results taken from a survey which formed part of a larger study. (n=176 hospital responses) The survey included both closed and open ended questions.	U.S.	Hospital	• Wrong patient • Dosage errors • Omission errors • Overlapping medication errors • Potential for errors to appear in multiple records (vs on paper where a mistake is usually limited to where it was written)	• Reduced scrutiny • Overdependence • Lack of flexibility • Lack of paper-based clues e.g. visiting a bedside to retrieve a drug chart • Alert fatigue • Loss of critical thinking • Lack of system integration	Yes
Ash et al. (2007)	**Categorizing the unintended sociotechnical consequences of computerized provider order entry**	To describe the unintended consequences related to the implementation of CPOE in the outpatient setting	Observations (29 hours of 13 clinicians) Interviews (15 hours of 12 individuals)	U.S.	Outpatient clinics	• Juxtaposition errors e.g. wrong route or wrong frequency	• Drop down menus • Alert fatigue	Yes
Baysari et al. (2012)	**Failure to utilize functions of an electronic prescribing system and the subsequent generation of 'technically preventable' computerized alerts**	To determine the frequency with which computerized alerts occur and the proportion triggered as a result of prescribers not utilizing e-	Medication chart review (2209 active orders)	Australi a	Hospital	• Duplicate orders	• Improper use of the system	No

			prescribing system's functions (Primarily a quantitative study, however the detailed examination of orders and judgement made about whether alerts were 'technically preventable' justified its inclusion in this review.)					
Campbell et al. (2006)	**Types of unintended consequences related to computerized provider order entry**	The purpose of this study was to identify and describe the major types of unintended adverse consequences related to CPOE implementation.	Five hospitals from 3 organisations Participant observations (390 hours of roughly 95 clinical providers) Semi-structured interviews (n=32 interviews) Conference discussions	U.S.	Hospital	• Juxtaposition errors • Improper data placement • Wrong patient	• Confusing order presentation • Pick lists • Workflow process mismatch • Incomplete display screens • Training	Yes
Caudill-Slosberg et al. (2005)	**Case study: Identifying potential problems at the human/ technical interface in complex clinical systems**	Presentation of a clinical scenario that demonstrates system vulnerability in the interface between humans and technology	Case Study: cause and effect/ fishbone analysis risk assessment	U.S.	Hospital	• Dose error	• Ambiguous dosing • The use of templates created a visual barrier to identifying the most important information • Incorrect assumption that the available readable	No

							information and copy and paste functions were correct.	
Chan et al.	Usability evaluation of order sets in a computerised provider order entry system	To perform a heuristic evaluation of a CPOE order set system to uncover existing usability issues prior to implementation.	Heuristic evaluation of a CPOE test platform according to 10 usability heuristics to identify usability problems. Observations and comments were documented.	Canada	Hospital (simulation study)	• Wrong orders	• Inconsistent error prevention • Lack of useful CDS	No
Cresswell et al. (2014)	Evaluation of medium-term consequences of implementing commercial computerised physician order entry and clinical decision support prescribing systems in two 'early adopter' hospitals	To understand the medium term consequences of implementing commercially produced CPOE and CDS in early adopter hospitals.	Case Study: Semi-structured interviews (n=43 users or implementers) Observations (n=21.5hours of strategic meetings and system use) Document analysis (n=11 documents)	U.K.	Hospital (n=2)	• Delayed treatment • Out of date medical records • Selection Errors • Duplicate Orders • Wrong Timing • Free-text errors	• Issues with system interoperability • Workarounds • Lack of system flexibility • Drop-down menus	Yes
Goldman et al. (2010).	Beyond the basics: Refills by electronic prescribing.	To evaluate healthcare providers opinions about the role of CPOE applications in improving patient safety and efficacy.	Mixed methods: Focus group: (n=64 focus groups of 276 participants) Survey: (n=157 participants)	U.S. Across six states	Ambulatory care (primary care)	• Medication and patient mix-ups • Selection errors	• Clumsy technology and the need to re-enter prescription information repeatedly • Interoperability issues • Reduced scrutiny of prescriptions. • Drop-down selection errors	Yes
Horsky et al. (2005)	Comprehensive analysis of a medication	To describe a dosing error event using a novel	Mixed analytical approach.	US	Hospital (secondary care)	• Overdose of potassium chloride	• Ambiguous use of language on data labels	Yes

	dosing error related to CPOE	approach to analysis.	1. Case review by the hospital safeguarding event committee. 2. Semi-structured interviews with clinicians involved in the incident (number not specified) 3. Analysis of order entry logs 4. Visual and cognitive evaluation of ordering screens			• Excessive duration of a potassium chloride infusion	• Similar features have important functional differences and were therefore easily confused • User-design mismatch (clinicians had a different understanding of certain terminology than the developers) • Free-text entries were not visible to other users • All medication orders cannot be viewed from one screen • Lack of emphasis on important information e.g. dates • A lack of user understanding about how to use the system effectively.	
Ja¨derlund Hagstedt et al. 2011	**Usability of computerised physician order entry in primary care: Assessing ePrescribing with a new evaluation model**	To develop and apply a model to evaluate the usability of different CPOEs used for ePrescribing in electronic health records (EHRs) in primary care.	1. Development of an evaluation model 2. Assessment of EHRs using the evaluation model 3. Interviews with prescribers (n=between 1 and 4 prescribers across the 7	Sweden	Primary Care	• Incomplete prescriptions • Misunderstanding of doses • Inappropriate drugs • Orders for the wrong patient	• Non-intuitive interfaces • Incorrect dosage functions • Ability to work on >1 patient at one time • Inadequate provision of drug allergy warnings	Yes

							Erroneous display of dosage • Reduced scrutiny of orders	
	The method was then applied to assess EHRs used in primary care.		different EHR systems)					
Khajouei et al. (2011)	Clinicians satisfaction with CPOE ease of use and effect on clinicians' workflow, efficiency and medication safety	To study the satisfaction of end-users of a CPOE system concerning ease of use and the effect on users' workflow, efficiency, and medication safety and to seek users' opinions regarding required improvements of the system. To determine whether there was a direct relation between user satisfaction and the results of a usability evaluation of the system.	Questionnaire including Likert-style questions, multiple choice answers and free-text responses (n=106 doctors; n= 327 nurses) NB: Reports on the results of one part of a larger piece of work; a literature review, observations, interviews and a usability evaluation was also conducted.	Netherlands	Hospital (secondary care)	• Dosing errors	• Suboptimal presentation of buttons used to calculate	Yes
Koppel et al (2005)	Role of computerized physician order entry systems in facilitating medication errors	To identify and quantify the role of CPOE in facilitating prescription error risks.	Mixed methods Quantitative: Survey: (n= 291 house staff who order medications via the system)	U.S.	Hospital (tertiary care)	• Wrong dose • Duplicate doses • Omitted doses • Gaps in therapy • Inappropriate medication • Selection errors • Wrong patient • Delayed doses	• Fragmented order screens • Erroneous assumed dose • Procedural linked medications • Lack of CDS warning to prompt antibiotic renewal	Yes

			Qualitative: o Interviews: (n=14 house staff; n=19 'expert participants') o Focus groups with house staff: (n=5 average group size, 10; range, 7-18) o Shadowing & Observation of order writing, charting and reviewing orders (n= 19, comprising of 4 house staff, 3 attending physicians, and 9 nurses and 3 pharmacists.					or warn clinicians about issues • Inappropriate timing of alerts • Incomplete display of a patient's medication list • Issues with the design of lists e.g. small font and long alphabetical lists. • Unclear login processes • Inflexible ordering processes.	
Nanji et al, (2013)	**Unrealized potential and residual consequences of electronic prescribing on pharmacy workflow in the outpatient pharmacy**	To identify and characterize the unrealized potential and residual consequences of electronic prescribing on pharmacy workflow in an outpatient pharmacy..	Interviews (n=6 retail pharmacy staff members) Observations (40 hours of 11 retail pharmacy staff)	U.S.	Community Pharmacy	• Missing or unclear doses • Missing or conflicting information • Repeat errors on refill prescriptions • Inappropriate drug choice • Wrong patient	• Incomplete display of drug name on the pharmacy system due to mismatch in text box size compared to the prescribers system. • Failure to update prescription changes on the prescribing system • Formulary issues	Yes
Odukoya et al. (2012)	**Relationship between e-Prescriptions and**	To understand how community pharmacy personnel use e-	Community Pharmacies (n=7 community pharmacies)	U.S.	Community Pharmacy	• Selection errors (wrong patient, drug, or dose) • Incomplete or duplicate directions	• Autofill functions • Poor display of free-text information	Yes

community pharmacy workflow	prescribing technology and to describe their perspectives regarding workflow challenges encountered when utilizing e-prescribing.	Pharmacy group interviews (seven group interviews with n=28 participants (Pharmacists n= 14; pharmacy technicians n= 14) Think aloud protocol (n=15 participants)				• Unclear directions		
Odukoya et al. (2013)	**e-Prescribing: Characterisation of patient safety hazards in community pharmacies using a sociotechnical systems approach**	To characterize the safety hazards related to e-prescribing in community pharmacies.	Total participants: n=40 (17 pharmacists and 23 technicians) Direct observations: (n=16 participants: 7 pharmacists and 9 pharmacy technicians) Think aloud Protocols: (n=16 participants: 7 pharmacists and 9 pharmacy technicians) Pharmacy team interviews: (n=7 group interviews, consisting of 2 pharmacists and 2 pharmacy technicians)	U.S	Community pharmacies (n=7)	○ Wrong strength ○ Wrong drug duration- ○ Wrong drug due to a selection error ○ Wrong formulation ○ Wrong patient: • Participants suggested that prescribers may have inputted or selected incorrect information such as dose, strength or formulation, which if not detected could have consequences for the patient.	• Multiple patient charts visible, therefore doctors may prescribe for the wrong patient. • Selection errors from lists • Communication issues between the pharmacist and prescriber may contribute to errors.	Yes
Odukoya et al. (2014)	**E-prescribing errors in community pharmacies: Exploring consequences and contributing factors**	To identify, in real time and retrospectively, medication errors associated with e-prescribing in community pharmacies, as	Direct observations (45 hours of 11 Pharmacists and 15 technicians) Semi-structured interviews (11	U.S.	Community Pharmacy (n=5 sites)	• Wrong drug • Wrong strength • Wrong pharmacy • Wrong prescriber notes • Wrong drug quantity • Wrong duration of therapy • Wrong dosing directions	• Receive duplicate or conflicting dosing directions • Incorrect calculation or entry of information • Auto-population functionality	Yes

		well as their potential consequences and contributing factors using a variety of data collection methods.	Pharmacists and 9 technicians)			• Wrong formulation	• Inadvertent entry or selection (drop-down menus) • Failure of prescribers to update re-fill prescriptions with changes • Mismatch between drug and patient information on prescribers system and pharmacy system. • Inadvertent mouse wheeling	
Robertson et al. (2014) [Conference abstract]	**A qualitative assessment of CPOE and the effects of variation in drug name display**	A study to assess drug name design and display issues in CPOE including: look-alike-sound-alike pairs, similar name adjacency errors, font, and visual display to better understand their potential to contribute to medication errors.	Assessment of leading vendor and home-grown CPOE systems in six major academic medical centres via remote walk-throughs and on-site visits. (n=10 CPOE systems in 6 US academic medical centers) Development of a CPOE assessment tool.	U.S.	Academic medical centres	• Drug name identification errors	• Inconsistent listing of drugs either by their brand or generic name • Inconsistent use of capital letters • Inability to order or search for drugs by a brand name • Unclear display of drug components in combination products • Lack of standardised font, text size or capitalisation across and within systems.	Yes
Savage et al. (2010)	**Medication errors with electronic prescribing: Two views of the same picture**	Compare the electronic prescribing medication error picture obtained with retrospective	Medication record review: (75 patients; 25 from each of general medicine, general surgery and paediatrics)	U.K.	Hospital	• Wrong patient • Wrong drug • Selection error • Dose, form, frequency error	• Default timings • Scrolling error • Loss of physical prompt by not visiting patient's bedside	Yes

		quantitative and qualitative methods.	Semi-structured interviews: (n=26 staff; n=19 patients)			• Duplication error • Omission errors	• Lack of CDS warnings • Drugs 'hidden' in order sets • Drop-down menus • Inflexible system • Issues with visibility of information on a screen	
Schiff et al. (2015)	**Computerised physician order entry-related medication errors: Analysis of reported errors and vulnerability testing of current systems.**	To (a) analyse medication error reports where CPOE was reported as a 'contributing cause' (b) develop 'use cases' based on the error reports to perform vulnerability testing of current CPOE systems.	Phase 1: Medmarx data analysis: taxonomy and coding of error reports (n=10,060 error reports) Phase 2: CPOE vulnerability testing on test-case scenarios (n=21 test case scenarios on 16 sites using 13 different CPOE systems)	U.S. and Canada	Phase 1: Multiple Phase 2: Inpatient and outpatient (16 sites)	• Incorrect instructions • Wrong dose/strength • Wrong schedule • Duplicate order • Wrong drug • Wrong route • Comment field issue • Wrong time • Wrong patient • Wrong formulation	• Multiple systems in use • Use of abbreviations • Failure to follow protocol • Inexperienced user/ training issues • Typing error • Paper and electronic hybrid system issues • System limitations • Lack of knowledge • Medicines reconciliation issues • Alert overrides • Transcription issues (copy and paste) • Free-text confusion • Order-set issues • Out of date/ incorrect drug dictionary • Initial continuing order issues • Misinterpretation	Yes

Schiff et al. (2012) **[Conference abstract]**	**CPOE-related medication errors: Analysis of 10,000 error report narratives and vulnerability testing of current systems**	Analysis and coding of the structured and narrative details of CPOE errors reported to the MEDMARX error reporting system	Analysis of CPOE-related medication error reports: (a) Qualitative and quantitative review of error content. (n=10,060 error reports) (b) Vulnerability testing of CPOE systems and creation of a taxonomy of CPOE errors by type, cause and prevention strategy (n=21 test case scenarios on 16 sites using 13 different CPOE systems)	U.S. and Canada	Various		• Missing information • Wrong dose/ strength • Wrong schedule • Duplicate orders • Wrong formulation/ dosage form • Free-text issues	• Multiple electronic systems in use • Abbreviations • Failure to follow protocol • Lack of computer training/ knowledge • Hybrid systems in use (paper and electronic) • Medicines reconciliation issues • Alert overrides.	Yes
Slight et al (2014) **[conference abstract]**	**Understanding the vulnerabilities of electronic prescribing systems for patient safety**	To identify and test the vulnerabilities of representative electronic prescribing systems to medication error, and to develop a more comprehensive understanding of how their design could be improved to advance patient safety.	Analysis of electronic prescribing associated error reports. (n=10,060 error reports) Vulnerability testing of test scenarios in different electronic prescribing systems (n=13, at 16 sites)	U.S. and Canada	Various		• Inappropriate drug choice/ combination • Wrong strength/ units	• Failure of the system to detect errors • Confusing wording of alert warnings • Issues with alert timing • Lack of consistency in the severity level of alert warnings • Workarounds	Yes

Study	Title	Aim	Methods	Country	Setting	Error types	Causes/Contributing factors	CDS
Slight et al. (2014) [Conference abstract	**A qualitative study exploring the vulnerabilities of computerized physician order entry systems**	To test the vulnerabilities of a wide range of CPOE systems to different types of medication errors, and to develop a more comprehensive understanding of how CPOE human factors design could be improved.	Entry of test scenarios (n=21) onto CPOE systems at 16 leading sites, in order to observe the ease or difficulty with which erroneous orders could be entered.	U.S. and Canada	Various	• Duplicate orders • Inappropriate drug/ combination	• Manner of order entry i.e. either structured or unstructured • Lack of CDS functionality • Confusing alert wording • Issue with the timing of alerts • Variable severity level assigned to alerts	Yes
Slight et al. (2013)	**The causes of prescribing errors in English general practices: a qualitative study**	To explore the causes of prescribing and monitoring errors and provide key recommendations for how they may be overcome.	Identification of potential prescribing and monitoring errors by pharmacists. Semi-structured interviews (n=34 participants) Focus groups (n=6, with 46 participants in total)	U.K.	Primary Care GP practices	• Selection errors	• Drop-down menus • Inappropriate alerts • Speed of the system	Yes
Snyder et al. (2011)	**An in-depth analysis of medication errors in hospitalized patients with HIV**	Determine the incidence of anti-retroviral therapy and opportunistic infection related medication errors and describe the nature and causes of these errors. To generate further quality improvement interventions	Prospective evaluation of the medication notes from patients stated to be on antiretroviral therapy to identify errors: (n=26 patients) Investigation of error causes: (n=69 antiretroviral or opportunistic infection related errors)	U.S.	Hospital	• Wrong dose • Missing information • Incorrect prescribing decision • Drug interactions • Wrong formulation/ strength • Wrong timing	• Medicines reconciliation issues • Lack of knowledge about the drug • Inappropriate drug information within the CDS system • Verbal or transcribing miscommunication • Alert overrides • Default timing	Yes

			Interviews with healthcare providers (number not stated) Expert panel review: (n=3 experts) to define the type and responsible step in the medication use process				
Vaziri et al. (2009)	**Are we setting about improving the safety of computerised prescribing in the right way? A workshop report.**	Evaluate the experience of UK primary healthcare professionals using clinical decision support software and to consolidate current technical opinion and literature in this area, with the aim of creating useful hypotheses to guide future academic investigation and industrial development.	Literature Review Multi-disciplinary workshop (n=30 delegates)	U.K.	Primary Care	• 'Prescribing errors'	• Nuisance alerts • Low specificity alerts • Alert fatigue • Cumbersome user interfaces	Yes

Author	Title	Aim	Methods	Country	Setting	Errors	Causes/Factors	
Vélez-Díaz-Pallarés et al. (2013)	**Using healthcare failure mode and effect analysis to reduce medication errors in the process of drug prescription, validation and dispensing in hospitalised patients.**	To identify actions to reduce medication errors in the process of drug prescription, validation and dispensing, and to evaluate the impact of their implementation.	Healthcare failure modes and effect analysis of the process of drug prescription, validation and dispensing. Before-after medication error study to determine the rate of medication errors, which were collected and classified by two observers. (n=1722 observations)	Spain	Hospital	• Wrong patient • Selection errors	• Lack of training or knowledge • Inappropriate default timing • Drop-down menus	Yes
Wentzer et al. (2007)	**Unintended transformations of clinical relations with a computerized physician order entry system**	To illuminate usability and utility problems of clinicians interacting with CPOE in real life settings.	Observations (n=48 hours on 2 internal medical wards) Semi-structured Interviews (n=6 interviews with 4 physicians and 2 nurses) Analysis of the user interface and other documents	Denmark	Hospital	• Wrong prescriber • Wrong units • Inappropriate drugs due to re-activation of completed treatments	• Clumsy PC tablet • Entering prescriptions in batches • User-access rights • Lack of system flexibility • Issues with the log-in process • Interface issues and lack of standardised way of displaying drug strength	Yes

Westbrook et al. (2013)	**The safety of electronic prescribing: manifestations, mechanisms, and rates of system-related errors associated with two commercial systems in hospitals**	To compare the manifestations, mechanisms and rates of system-related errors associated with two electronic prescribing systems. To determine if the rates of system-related prescribing errors is greater than the rate of errors prevented	Medication chart review to identify errors (n=629 inpatient admissions) Development of an error-mechanism classification. Classification of the errors according to the types of mechanism leading to the error.	Australia	Hospital	• Selection errors (wrong drug, wrong strength, wrong route) • Wrong time • Wrong frequency • Wrong formulation • Duplicate order	• Drop-down menu • Failure to change the default time/ date • System limitations • Incorrect element of an order sentence due to errors made when editing or constructing an order • Errors associated with ancillary information • Incorrect information contained within the electronic prescribing system.	Yes
Wetterneck et al. (2011)	**Factors contributing to an increase in duplicate medication order errors after CPOE implementation.**	To evaluate the incidence of duplicate medication orders before and after CPOE with CDS implementation and identify contributing factors.	Prospective pre-intervention, post-intervention observational trial: (n=630 patients) Medication chart review- events were assessed to determine whether an error had occurred, the stage at which the error occurred and the type of error. Content analysis of all duplicate orders: (n=167 duplicate orders post CPOE implementation) Survey questionnaire using Likert style	U.S.	Hospital	• Duplicate orders	• Duplicate prescribers working simultaneously on different computers • Items 'hidden' in order sets • Failure of CDS to check new orders against completed orders • CDS does not trigger alerts for duplicate orders for different routes of administration • Improper use of the system (failure to discontinue a previous IV order	Yes

			questions: (n= 51 providers responded, 3 months post-CPOE implementation and n=53 providers responded, 1 year post CPOE implementation				• when the route is changed to oral. • Misleading design and content of alerts • Issues with the timing of alerts	
Zhan et al. (2006)	**Potential benefits and problems with computerized prescriber order entry. Analysis of a voluntary medication error-reporting database.**	To assess the potential benefits and problems associated with CPOE using a voluntary medication-error reporting system. Also to explore the potential value and proper use of voluntary error reporting in patient safety research.	Comparison of the number of medication errors reported from facilities that had CPOE in place and those that did not (n= 235,164 error reports) Examination of the characteristics of reported errors that were caused by CPOE (n=7029 CPOE related medication errors) Qualitative analysis of error reports.(n=7029 CPOE related medication errors)	U.S.	Hospitals and Healthcare systems	• Dose errors • Wrong formulation • Extra doses • Wrong patient • Wrong time • Unauthorised drug • Wrong strength	• Lack of knowledge • Use of abbreviations • Dose calculations • Lack of CDS • Distraction • Computer interface • Interoperability issues • Drop-down menus	Yes
Abbreviations								
CPOE	**Computerized Provider Order Entry**			**CDS**	**Clinical Decision Support**		**EHR**	**Electronic Health Record**

Appendix 6: Factors contributing to medication errors made when using computerized order entry in paediatrics: a systematic review

OXFORD

Review

Factors contributing to medication errors made when using computerized order entry in pediatrics: a systematic review

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ABSTRACT

Objective: To identify and understand the factors that contribute to medication errors associated with the use of computerized provider order entry (CPOE) in pediatrics and provide recommendations on how CPOE systems could be improved.

Materials and Methods: We conducted a systematic literature review across 3 large databases: the Cumulative Index to Nursing and Allied Health Literature, Embase, and Medline. Three independent reviewers screened the titles, and 2 authors then independently reviewed all abstracts and full texts, with 1 author acting as a constant across all publications. Data were extracted onto a customized data extraction sheet, and a narrative synthesis of all eligible studies was undertaken.

Results: A total of 47 articles were included in this review. We identified 5 factors that contributed to errors with the use of a CPOE system: (1) lack of drug dosing alerts, which failed to detect calculation errors; (2) generation of inap- propriate dosing alerts, such as warnings based on incorrect drug indications; (3) inappropriate drug duplication alerts, as a result of the system failing to consider factors such as the route of administration; (4) dropdown menu selection errors; and (5) system design issues, such as a lack of suitable dosing options for a particular drug.

Discussion and Conclusions: This review highlights 5 key factors that contributed to the occurrence of CPOE- related medication errors in pediatrics. Dosing support is the most important. More advanced clinical decision support that can suggest doses based on the drug indication is needed.

Key words: computerized provider order entry, clinical decision support, pediatrics, medication errors, patient safety

Appendix 7: Search Strategy for Factors contributing to medication errors made when using computerized order entry in paediatrics: a systematic review as conducted in Embase (Ovid)

Full Search Strategy: Embase (Ovid)

1. computerized prescriber order entry.mp
2. exp computerized provider order entry/
3. Electronic physician order entry.mp.
4. electronic order entry.mp.
5. exp electronic prescribing/
6. electronic prescription.mp.
7. computerized physician order entry.mp.
8. CPOE.mp.
9. computerized order entry.mp.
10. Medical order entry systems.mp.
11. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10
12. clinical decision support.mp.
13. exp decision support system/
14. decision support system.mp.
15. exp computer assisted drug therapy/
16. 12 or 13 or 14 or 15
17. exp electronic medical record/
18. electronic health record.mp.
19. electronic patient record.mp.
20. 17 or 18 or 19
21. paediatrics.mp.
22. exp pediatrics/
23. paediatric.mp.
24. child/
25. infant/
26. adolescent/
27. 21 or 22 or 23 or 24 or 25 or 26
28. 11 or 16 or 20
29. exp medication error/
30. medication error.mp.
31. unintended consequence.mp.
32. 29 or 30 or 31
33. 27 and 28 and 32

34.   limit 33 to english language

Appendix 8: Data extraction table for: factors contributing to medication errors made when using computerized order entry in paediatrics: A systematic review

	Author	Title	Reference	Country	Methods and Setting	Key issues identified of interest
1.	Abboud P.A. et al.	Impact of workflow-integrated corollary orders on aminoglycoside monitoring in children.	Health Informatics Journal. 12 (3) (pp 187-198), 2006. Date of Publication: September 2006.	U.S.	Quantitative pre-post study design to examine the impact of an electronic workflow-integrated aminoglycoside corollary order Major 423 bed tertiary care children's hospital	Lack of monitoring Poor design of corollary orders Lack of workflow-integrated clinical decision support tools designed according to human factors design principles.
2.	Apkon M et al.	Design of a safer approach to intravenous drug infusions: failure mode effects analysis.	Quality & Safety in Health Care. 13(4):265-71, 2004 Aug.	U.S.	Staff quantitative survey and Failure Modes and Effects Analysis 11 bed paediatric ICU in a children's hospital	Dosing Errors CPOE unable to support calculation at the time of ordering. Manual transfer of calculated dose/rate combinations into the CPOE system
3.	Caruso MC et al.	Pediatric emergency department discharge prescriptions requiring pharmacy clarification.	Pediatric Emergency Care. 31(6):403-8, 2015 Jun.	U.S.	Quantitative Retrospective chart review 44-bed paediatric emergency department with 14 over flow beds and 4 trauma bays.	Dosing Errors Unclear instructions Drug allergy Drug interactions Lack of automated dosage check by CPOE system.

4.	Cochran GL et al.	From physician intent to the pharmacy label: prevalence and description of discrepancies from a cross-sectional evaluation of electronic prescriptions.	BMJ Quality & Safety. 23(3):223-30, 2014 Mar.	U.S.	Quantitative Retrospective cross-sectional study Three ambulatory care clinic-community pharmacy pairs.	Discrepancies were more frequent in peditaric clinics compared to adult clinics. Oral liquids were commonly associated with discrepancies as well as creams and eye drops. Duration of therapy and administration directions, and wrong drug errors were reported. Free text option appeared to contribute to errors.
5.	Condren M et al.	Influence of a systems-based approach to prescribing errors in a pediatric resident clinic.	Academic pediatrics. 14(5):485-90, 2014 Sep-Oct.	U.S	Quantitative. Retrospective comparative study. Two general paediatric clinics	Dosing Errors Liquid medications more error prone due to calculation errors. Automated dose rounding to the nearest teaspoon rather than nearest millilitre.
6.	Doherty C Mc Donnell C	Tenfold medication errors: 5 years' experience at a university-affiliated pediatric hospital.	Pediatrics. 129(5):916-24, 2012 May.	Canada	Quantitative with investigation of error causes Evaluation of all voluntary reports of medication related safety reports in a 300-bed quaternary paediatric centre.	10- fold under and over dose errors Overrides of CPOE and CDS warnings. CPOE failed to block prescription
7.	Doherty C. McDonnell C.	Tenfold medication errors in pediatric hospital practice.	Canadian Journal of Anesthesia. Conference: 2011 Annual Meeting of the Canadian Anesthesiologists' Society, CAS Toronto, ON Canada. Conference Start: 20110624 Conference End: 20110628. Conference Publication: (var.pagings). 58 (pp S168), 2011. Date of Publication: June 2011.	Canada	Quantitative with investigation of error causes Reports describing 10 fold medication errors were further analysed – drug class, under/overdose, outcome and whether it had reached the patient. Severity of error was calculated.	10- fold under and over dose errors Overrides of CPOE and CDS warnings.

8.	Ekedahl A. et al.	Problem prescriptions in Sweden necessitating contact with the prescriber before dispensing.	Research in Social and Administrative Pharmacy. 6 (3) (pp 174-184), 2010. Date of Publication: September 2010.	Sweden	Quantitative Observational study to record instances where pharmacists had to contact prescribers for clarification before dispensing 7 hospital pharmacies and 7 city pharmacies, in Sweden.	Younger patients had the highest rate of contact needed. Errors included wrong product (drug, strength, admin form) and insufficient information. Juxtaposition selection errors
9.	Gattari T.B. et al.	Medication discrepancies at pediatric hospital discharge.	Hospital Pediatrics. 5 (8) (pp 439-445), 2015. Date of Publication: 01 Aug 2015.	U.S.	Quantitative prospective study to determine the discrepancy rates at the time of discharge when multiple sources of medication documentation exist. Inpatients admitted to a defined general paediatric inpatient floor. Staying over 24 hours.	Document discrepancies Addition/ omission errors Dose errors
10.	Ginzburg R et al.	Effect of a weight-based prescribing method within an electronic health record on prescribing errors.	American Journal of Health-System Pharmacy. 66(22):2037-41, 2009 Nov 15.	U.S.	Quantitative Before and after study after introductions of a weight based clinical decision support tool for certain medications. One institution comprising of multiple family medicine clinics throughout the New York area; patients	Dose errors Incomprehensible dosing instructions
11.	Han Y.Y. et al.	Unexpected increased mortality after implementation of a commercially sold computerized physician order entry system.	Pediatrics. 116 (6) (pp 1506-1512), 2005. Date of Publication: Dec 2005.	U.S.	Quantitative, retrospective study Evaluation of mortality rates among children who were admitted via interfacility transport before and after CPOE implementation.	Increased mortality Delays in patient care Workflow changes

12.	Holdsworth MT et al.	Impact of computerized prescriber order entry on the incidence of adverse drug events in pediatric inpatients.	Pediatrics. 120(5):1058-66, 2007 Nov.	U.S	Quantitative, prospective chart review	Dose error Drug-knowledge failures Medication tracking issues Inappropriate design of dosing support
13.	Hou J.-Y. et al.	The effect of a Computerized pediatric dosing decision support system on pediatric dosing errors.	Journal of Food and Drug Analysis. 21 (3) (pp 286-291), 2013. Date of Publication: September 2013.	Taiwan	Quantitative. Comparison of medication orders made using a CPOE system alone and a CPOE system with paediatric dosing decision support One hospital outpatient setting	Dosing errors Selection errors Inappropriate alert overrides
14.	Jani Y.H. et al.	Paediatric dosing errors before and after electronic prescribing.	Quality & safety in health care. 19 (4) (pp 337-340), 2010. Date of Publication: Aug 2010.	U.K.	Quantitative. Before and after study; comparison of the incidence and severity of paediatric dosing errors before and after implementation of CPOE with basic CDS. 314 bed acute tertiary care paediatric hospital	Dose errors Lack of knowledge Selection errors from drop-down menus.
15.	Jani Y.H. et al.	Republished error management: Paediatric dosing errors before and after electronic prescribing.	Postgraduate Medical Journal. 87 (1030) (pp 565-568), 2011. Date of Publication: August 2011.	U.K.	Quantitative. Before and after study; comparison of the incidence and severity of paediatric dosing errors before and after implementation of CPOE with basic CDS. 314 bed acute tertiary care paediatric hospital	Dose errors Lack of knowledge Selection errors from drop-down menus.

16.	Jani Y.H. et al.	Electronic Prescribing Reduced Prescribing Errors in a Pediatric Renal Outpatient Clinic.	Journal of Pediatrics. 152 (2) (pp 214-218), 2008. Date of Publication: February 2008.	U.K.	Quantitative Prospective before-and-after study conducted in a nephrology outpatient clinic at an acute tertiary care paediatric hospital	Omission errors Dose errors Frequency/ direction errors Selection errors Duplicate alerts did not detect duplicate doses if second order had different strength or formulation of the same drug.
17.	Kadmon G et al.	Computerized order entry with limited decision support to prevent prescription errors in a PICU.	Pediatrics. 124(3):935-40, 2009 Sep.	Israel	Quantitative Retrospective pre-post study of prescription error rates pre-CPOE, post CPOE and post CPOE and CDS in a 12 bed PICU	Dose errors CDS needed for significant reduction in errors Lack of under dose CDS Missing signature errors- lack of mandatory function
18.	Kaestli LZ et al.	Prospective risk analysis and incident reporting for better pharmaceutical care at paediatric hospital discharge.	International Journal of Clinical Pharmacy. 36(5):953-62, 2014 Oct.	Switzerland	Failure Modes and Effect Causality Analysis (FMECA) of the paediatric medication discharge process by a multidisciplinary team. The analysis focused on the entire medication process, from prescription at the hospital to drug administration at home, with special attention given to drug delivery by the community pharmacy Incidents that occurred over 46 months and were reported by community pharmacists were classified according to the FMECA.	Dose error Lack of CDS warning

#	Author	Title	Source	Country	Methodology	Findings
19.	Kazemi A et al.	The effect of Computerized Physician Order Entry and decision support system on medication errors in the neonatal ward: experiences from an Iranian teaching hospital.	Journal of Medical Systems. 35(1):25-37, 2011 Feb.	Iran	Quantitative Comparison of the effect of Computerized Physician Order Entry (CPOE) without and with decision support functionalities in reducing non-intercepted medication dosing errors in antibiotics and anticonvulsants Qualitative discussions with prescribers 17 bed neonatal ward	Wrong dose Calculation errors Mis-selection Dose adjustment difficulties Failure to update the dose based on the patient's current age Alert overrides
20.	Kazemi A et al.	Physician order entry or nurse order entry? Comparison of two implementation strategies for a computerized order entry system aimed at reducing dosing medication errors.	Journal of Medical Internet Research. 12(1):e5, 2010.	Iran	Prospective Quantitative 17 bed neonatal ward Comparison of medication error rate when physician order entry was followed by nurse verification or nurse order entry followed by physician verification and counter signature.	Dose errors Wrong interval Alert overrides Other errors occurred when one or more of the dose decision criteria (age, weight, GFR, etc.) had changed since the last prescription but the prescriber did not change the prescribed order and repeated the previously ordered dose and frequency.
21.	Killelea BK et al.	To what extent do pediatricians accept computer-based dosing suggestions?.	Pediatrics. 119(1):e69-75, 2007 Jan.	U.S.	Quantitative Retrospective analysis of all electronic medication orders entered into a CPOE system over an 8-month period. General urban teaching hospital; paediatric inpatient service.	Dosing alert overrides. Lack of context specific dosing. Absence of patient weight in the system, which prevented certain checks from being performed.

22.	Kim G.R. et al.	Error reduction in pediatric chemotherapy: Computerized order entry and failure modes and effects analysis.	Archives of Pediatrics and Adolescent Medicine. 160 (5) (pp 495-498), 2006. Date of Publication: May 2006.	U.S.	Quantitative Before and after study Failure Modes and Effects Analysis pre-post CPOE Paediatric Oncology department in one hospital	After CPOE implementation, there was a higher risk of medication orders not matching the patient's treatment plan, this was due to: i. No automated drug-protocol linkage ii. New or experimental drugs did not appear on the predefined CPOE menu, requiring users to enter them manually.
23.	Kirk RC et al.,	Computer calculated dose in paediatric prescribing.	Drug Safety. 28(9):817-24, 2005.	Singapore	Quantitative Prospective cohort study. Paediatric unit in a university teaching hospital	Dose errors Manual adjustment of computer calculated doses Overrides/ ignoring alerts
24.	Kirkendall ES et al.,	Evaluating the accuracy of electronic pediatric drug dosing rules.	Journal of the American Medical Informatics Association. 21(e1):e43-9, 2014 Feb.	U.S.	Quantitative, Retrospective cross-sectional review of medication orders and alerts 577-bed quaternary care medical centre	High proportion of potentially inaccurate doses within CPOE CDS system. Only 55.1% of eRules matched gold standard.
25. 26.	Maat B et al.,	Clinical pharmacy interventions in paediatric electronic prescriptions.	Archives of Disease in Childhood. 98(3):222-7, 2013 Mar.	The Netherlands	Quantitative Prospective cohort study with nested case control study. Tertiary Children's hospital	Completion errors (e.g., body weight missing) Dose errors Wrong formulation Wrong route of administration Wrong drug Drug-drug interactions Free-text entry was more commonly associated with an intervention Younger patients (0-2 years) had a higher risk of intervention. Oral dosage forms and oral routes of administration were methods with a relatively high risk of intervention.

27.	Manriq ue-Rodrigu ez S et al.,	Smart pump alerts: all that glitters is not gold.	International Journal of Medical Informatics. 81(5):344-50, 2012 May.	Spain	Quantitative evaluation of the use of smart infusion pumps 11 bed PICU	Inappropriate CDS warnings Dose limits did not account for normal dose rounding.
28.	McPhilli ps HA et al.	Potential medication dosing errors in outpatient pediatrics.	Journal of Pediatrics. 147(6):761-7, 2005 Dec.	U.S.	Quantitative Review of automated pharmacy data from 3 health maintenance organizations for 120 children with a new dispensing prescription for 22 medications of interest.	No difference in potential medication error dosing error rate between an organization with CPOE without child specific CDS did not have a lower potential medication dosing error rate compared to the organisations using handwritten prescriptions Prescribers still had to calculate and enter weight-based doses for most drugs.
29.	Mille, Frederic et al.,	Analysis of overridden alerts in a drug-drug interaction detection system.	International Journal for Quality in Health Care. 20(6):400-5, 2008 Dec.	France	Quantitative and qualitative prospective analysis of overridden CDS alerts	High alert override rate; including high false-positive alerts. Lack of context specific alerts e.g., did not take into consideration the date and time of administration, so could not identify active drug-interactions Alerts lacked important information within the recommendations for the management of drug-interactions
30.	Nelson, Courtne y E et al.	Electronic prescription writing errors in the pediatric emergency department.	Pediatric Emergency Care. 31(5):368-72, 2015 May.	U.S	Quantitative Retrospective chart review of a random selection of electronic prescriptions written in a paediatric emergency department.	Incomplete directions and dose/direction errors were the most common error types (37% of all errors) CPOE did not rule out all significant clinical errors Incomplete drug directions were still seen due to the option to free-text The persistence of dosing and direction errors suggest that residents are not effectively using the resources connected to the CPOE and were possibly bypassing alerts

31.	Pacheco G.S. et al.	The effects of resident level of training on the rate of pediatric prescription errors in an academic emergency department.	Journal of Emergency Medicine. 43 (5) (pp e343-e348), 2012. Date of Publication: November 2012.	U.S.	Quantitative Retrospective review of computer based outpatient prescriptions in an academic emergency department.	Dosing errors Errors made during the calculation of weight based doses
32.	Patterson, Emily S., et al.	Enhancing Electronic Health Record Usability in Pediatric Patient Care: A Scenario-Based Approach.	Joint Commission Journal on Quality & Patient Safety (JOINT COMM J QUAL PATIENT SAF), 2013 Mar; 39(3): 129-135. (7p)	U.S.	An iterative, scenario-based approach was used to identify unique considerations in paediatric care and relevant human factors concepts by panel members with expertise in human factors, usability, informatics, paediatrics, ambulatory care and paediatric intensive care	Dose error Patient miss-identification Vaccination errors Wrong drug Avoid truncating information One-click growth chart Avoid automated changes to default dose Safeguards to prevent orders for the wrong units Decision Support for dosing low-weight patients Allow entry of medical history data received atother institutions.
33.	Potts, Amy L et al.,	Computerized physician order entry and medication errors in a pediatric critical care unit.	Pediatrics. 113(1 Pt 1):59-63, 2004 Jan.	U.S	Quantitative, prospective cohort study. Comparison of the medication error rate at the ordering stage before and after implementation of a CPOE system in a paediatric critical care unit.	Dose Error Interval Error Lack of CDS e.g., age or indication specific dosing support
34.	Russell R.A. et al.	Impact of Computerized Order Entry to Pharmacy Interface on Order-Infusion Pump Discrepancies.	Journal of Drug Delivery. 2015 (no pagination), 2015. Article Number: 686598. Date of Publication: 2015.	U.S.	Quantitative uncontrolled before and after study utilizing a prospective, observational design 72 bed paediatric intensive care unit	An increase in the proportion of omitted medications post-intervention. Workflow issues associated with CPOE

35.	Russell, Rebecca A et al.	Discrepancies between medication orders and infusion pump programming in a paediatric intensive care unit.	Quality & Safety in Health Care. 19 Suppl 3:i31-5, 2010 Oct.	U.S.	Quantitative Discrepancies between medication orders and infusion pump programming in a paediatric intensive care unit. 30 bed paediatric intensive care unit	Omission or incorrect order entry
36.	Sard, Brian E et al.	Retrospective evaluation of a computerized physician order entry adaptation to prevent prescribing errors in a pediatric emergency department.	Pediatrics. 122(4):782-7, 2008 Oct.	U.S.	Quantitative Retrospective cohort study; comparison or orders before and after introduction of a quick list. Staff survey	Dosing Errors Frequency Errors Route Errors Missing information Users override mandatory fields Users changed information on the quick list Free-text entry
37.	Scharn weber C. et al.	Evaluation of medication dose alerts in pediatric inpatients.	International Journal of Medical Informatics. 82 (8) (pp 676-683), 2013. Date of Publication: August 2013.	U.S	Quantitative Review of medication orders and medication dose alert data Rate of alert presentation and provider response was recorded 188 bed tertiary care paediatric hospital NB: in this study paediatrics were classified as those <21 years old.	Inappropriate under/ overdose alert presentation Inappropriate information in the database e.g., the most recent dose of erythromycin dose when used as a motility agent Poorly designed alerts Alert fatigue
38.	Sethura man, Usha et al.	Prescription errors before and after introduction of electronic medication alert system in a pediatric emergency department.	Academic Emergency Medicine. 22(6):714-9, 2015 Jun.	U.S	Quantitative Prospective before and after study of outpatient medication prescriptions Paediatric emergency department in a free-standing children's hospital that is a level I trauma centre	Dose errors Inappropriate alert presentation Alert overrides, and false-positive alerts Alerts did not consider the drug indication
39.	Stultz J.S. et al.	Sensitivity and specificity of dosing alerts for dosing errors among	Journal of the American Medical Informatics	U.S.	Quantitative Review of orders and medication dosing alerts, reported ADEs	Dose errors Inappropriate alerts False positive alerts

		hospitalized pediatric patients.	Association : JAMIA. 21 (e2) (pp e219-225), 2014. Date of Publication: Oct 2014.		and pharmacist-detected dosing errors. Academic paediatric tertiary referral centre with over 350 beds, including neonatal and paediatric intensive care units, emergency department and other specialised inpatient units.	Lack of indication based dosing CDS
40.	Stultz, Jeremy S et al.	Appropriateness of commercially available and partially customized medication dosing alerts among pediatric patients.	Journal of the American Medical Informatics Association. 21(e1):e35-42, 2014 Feb.	U.S.	Quantitative Review of pharmacy records Each order that caused a dosing alert to be presented was identified and reviewed Tertiary paediatric hospital with over 350 beds including paediatric intensive care units, an emergency department, and other specialised inpatient units	Dose errors Inappropriate alerts False positive alerts Dosing CDS, which was not based on the formulation, failed to consider factors such as pre-menstrual age.
41.	Taylor, James A et al.	Medication administration variances before and after implementation of computerized physician order entry in a neonatal intensive care unit.	Pediatrics. 121(1):123-8, 2008 Jan.	U.S	Quantitative Prospective, before/after observational study Variances between the order and what was administered were recorded, reasons for the variance was also classified. 30 bed- Neonatal intensive care unit	Dose error Omission errors Timing error Route of administration error No specific cause attributed to CPOE
42.	Tora, Hammar et al.	Potential drug related problems detected by electronic expert support system in patients with multi-dose drug dispensing.	International Journal of Clinical Pharmacy. 36(5):943-52, 2014 Oct.	Sweden	Quantitative Review of drugs dispensed and alerts generated for all patients in Sweden with multi-dose drug dispensing Sweden's national prescription repository	Wrong dose Drug interactions Paediatric warnings Duplications Drug disease inferred Potential lack of CDS

43.	Vaidya, Vinay et al.	Evaluating the safety and efficiency of a CPOE system for continuous medication infusions in a pediatric ICU.	AMIA … Annual Symposium Proceedings/ AMIA Symposium. 1128, 2006.	US	Quantitative Paediatric ICU	Missing prescriber's signature
44.	van Tilburg, C M et al.	Health Care Failure Mode and Effect Analysis: a useful proactive risk analysis in a pediatric oncology ward.	Quality & Safety in Health Care. 15(1):58-63, 2006 Feb.	Nethe rlands	Healthcare Failure Modes and Effect Analysis 11- members of a multidisciplinary team	Wrong dose Miss calculation
45.	Walsh K.E. et al.	Medication errors related to computerized order entry for children.	Pediatrics. 118 (5) (pp 1872-1879), 2006. Date of Publication: November 2006.	U.S.	Quantitative Retrospective review of medication orders, admissions and hospital incident reports. Urban teaching hospital, 40 general and surgical paediatric inpatient beds, 4 paediatric intensive care unit beds and 15 neonatal intensive care unit beds.	Wrong dose- key pad entry error Alert overrides Selection errors from a drop-down menu Order set errors- orders erroneously prescribed due to 'select all' functionality. Lack of patient specific CDS Duplicate dose error due to a lack of flexibility in the computer order system
46.	Walsh K.E. et al.	Effect of computer order entry on prevention of serious medication errors in hospitalized children.	Pediatrics. 121 (3) (pp e421-e427), 2008. Date of Publication: March 2008.	U.S.	Interrupted time-series regression analysis, review of charts, orders and incident reports Neonatal intensive care unit, paediatric intensive care unit and inpatient paediatric wards	Dose errors Human-machine interface problems
47.	Warrick, Catheri ne et al.	A clinical information system reduces medication errors in paediatric intensive care.	Intensive Care Medicine. 37(4):691-4, 2011 Apr.	U.K.	Quantitative Prospective audit of prescribing errors and dose omissions Paediatric intensive care unit	Incorrect infusion rate selection No base solution prescribed Selection error from a drop-down menu

| 48. | Webber, E C et al. | Conversion of a single-facility pediatric antimicrobial stewardship program to multi-facility application with computerized provider order entry and clinical decision support. | Applied Clinical Informatics. 4(4):556-68, 2013. | U.S. | Quantitative

Evaluation of electronic power plans including weight-based dosing and empiric indication-based recommendations.

9 facilities within a paediatric academic centre that care for paediatric or neonatal patients. | CPOE-related medication variances

Incorrect order-sentence

Interface issues- monitoring system change, training gaps and workflow issues. |

Appendix 9: A literature review of the training offered to qualified prescribers to use electronic prescribing systems: Why is it so important?

Clare L. Brown[a,b], Katie Reygate[c], Ann Slee[d,e], Jamie J. Coleman[e], Sarah K. Pontefract[e], David W. Bates[f,g,h], Andrew K. Husband[e], Neil Watson[b] and Sarah P. Slight[a,b,f]

Division of Pharmacy, School of Medicine, Pharmacy and Health, Durham University, Stockton on Tees, [b]Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle Upon Tyne, [c]Health Education KSS Pharmacy, Princess Royal Hospital, West Sussex, [d]eHealth Research Group, Centre for Population Health Sciences, University of Edinburgh, Edinburgh, [e]College of Medical and Dental Sciences, University of Birmingham, Birmingham, UK, [f]Division of General Internal Medicine, The Center for Patient Safety Research and Practice, Brigham and Women's Hospital, gHarvard Medical School, and [h]Harvard School of Public Health, Boston, MA, USA

Abstract

Objectives A key element of the implementation and ongoing use of an elec- tronic prescribing (ePrescribing) system is ensuring that users are, and remain, sufficiently trained to use the system. Studies have suggested that insufficient training is associated with suboptimal use. However, it is not clear from these studies how clinicians are trained to use ePrescribing systems or the effective- ness of different approaches. We sought to describe the various approaches used to train qualified prescribers on ePrescribing systems and to identify whether users were educated about the pitfalls and challenges of using these systems.

Methods We performed a literature review, using a systematic approach across three large databases: Cumulative Index Nursing and Allied Health Literature, Embase and Medline were searched for relevant English language articles. Arti- cles that explored the training of qualified prescribers on ePrescribing systems in a hospital setting were included.

Key findings Our search of 'all training' approaches returned 1155 publica- tions, of which seven were included. A separate search of 'online' training found three relevant publications. Training methods in the 'all training' cate- gory included clinical scenarios, demonstrations and assessments. Regarding 'online' training approaches; a team at the University of Victoria in Canada developed a portal containing simulated versions of electronic health records, where individuals could prescribe for fictitious patients. Educating prescribers about the challenges and pitfalls of electronic systems was rarely discussed.

Conclusions A number of methods are used to train prescribers; however, the lack of papers retrieved suggests a need for additional studies to inform training implementation.

Appendix 10: Search Strategy for 'All training' search from Medline (Ovid) database

Keyword terms were searched across *'af'* (all fields).

1. Computerized prescriber order entry
2. Computerized provider order entry/
3. Electronic physician order entry
4. Electronic order entry
5. Electronic prescribing/
6. Electronic prescription
7. Computerized physician order entry
8. CPOE
9. Computerized order entry
10. Medical order entry systems
11. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10
12. Clinical decision support
13. Decision support system/
14. CDS
15. Drug therapy, computer assisted
16. 12 or 13 or 14 or 15
17. Electronic medical record/
18. Electronic health record
19. Electronic patient record
20. 17 or 18 or 19
21. Education/
22. Clinical education/
23. Training/
24. Course
25. Competence/
26. Medical education/
27. Clinical competence/
28. Competence assessment
29. Prescriber training
30. Prescriber assessment
31. 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34
32. 11 or 16 or 20
33. 31 and 32
34. Limit to English language

Appendix 11: Articles included and excluded following review of abstract and full text for a literature review of the training offered to qualified prescribers to use electronic prescribing systems

Articles included and excluded following review of abstract: All Training

Number	Paper (Author, Year)	Title	Database	Study Type	Country	Justification for exclusion
Publications excluded after review of abstracts						
1	Avery AJ, 2014	Research into practice: Safe prescribing.	Embase	Report Summary	UK	Primary care Lack of focus on training and competency on an electronic prescribing system
2	Baysari MT, 2012	Understanding doctors' perceptions of their prescribing competency and the value they ascribe to an electronic prescribing system.	Medline Embase	Qualitative	Australia	Lack of focus on training and competency on an electronic prescribing system
3	English T, 2010	Obstacles to Rolling Out an EMR in a Residency.	Embase			Non- hospital setting Lack of focus on training and competency on an electronic prescribing system
4	Haffey F, 2014	Smartphone apps to support hospital prescribing and pharmacology education: A review of current provision.	Embase		UK	Lack of focus on training and competency on an electronic prescribing system
5	Kamerow D, 2010	What i learnt from mom.	Embase	Viewpoint	US	Lack of relevance

6	Kaur D, 2015	E learning: Moving towards a technologically advanced and progressive psychiatry!.	Embase	Conference; workshop	India	Lack of focus on training and competency on an electronic prescribing system
7	Larson KA, 2004	Reducing medication errors in a surgical residency training program.	Embase Medline	Qualitative	US	Hospital not using EP, not relevant to training/ prescribing competency
8	Miller AS, 2003	The training process (Part 1).	Embase			Unable to access
9	Ross S, 2012	Prescribing and the core curriculum for tomorrow's doctors: BPS curriculum in clinical pharmacology and prescribing for medical students.	Embase	Review	UK	Lack of relevance for qualified prescribers and electronic systems
10	Adibe BA, 2010	Electronic health records: potential to transform medical education.	Medline	Supplementary piece, commentary	US	Lack of focus on training and competency on an electronic prescribing system
11	Bloice MD, 2014	Casebook: a virtual patient iPad application for teaching decision-making through the use of electronic health records.	Medline	Learning Tool Development	Austria	Lack of focus on training and competency on an electronic prescribing system
12	Chi J, 2014	Clinical education and the electronic health record: the flipped patient.	Medline CINAHL	Opinion piece.	US	Lack of focus on training and competency on an electronic prescribing system
13	Elliott K, 2011	A student-centred electronic health record system for clinical education.	Medline	Qualitative	Australia	Lack of relevance for qualified doctors Lack of focus on training and competency on an electronic prescribing system
14	Han H, 2013	Writing and reading in the electronic health record: an entirely new world.	Medline	Qualitative	US	Lack of focus on training and competency on an electronic prescribing system

15	Hart J, 2010	University of Arkansas for Medical Sciences electronic health record and medical informatics training for undergraduate health professionals.	Medline CINAHL	Report	US	Lack of relevance for qualified doctors/ prescribers
16	Keenan CR, 2006	Electronic medical records and their impact on resident and medical student education.	Medline	Literature Review	US	Lack of focus on training and competency on an electronic prescribing system
17	Knight AM, 2012	The effect of computerised provider order entry on medical student's ability to write orders.	Medline	Comparative study	US	Lack of relevance for qualified doctors
18	Knight AM, 2007	The good news about CPOE and medical student ordering ability.	Medline	Comparative study	US	Lack of relevance for qualified doctors
19	Morrison F, 2011	Developing an online and in-person HIT workforce training program using a team-based learning approach.	Medline	Qualitative	US	Lack of focus on training and competency on an electronic prescribing system
20	Moser SE, 2010	Precepting medical students in the era of EHRs.	Medline	Report	US	Lack of relevance for qualified prescribers
21	Pageler NM, 2013	Refocusing medical education in the EMR era.	Medline	Viewpoint	US	Lack of focus on training and competency on an electronic prescribing system (focus on EMR)
22	Pippitt K, 2013	Medical student education in the EMR era requires access to the EMR.	Medline	Comment; letter	US	Lack of relevance for qualified doctors Lack of focus on training and competency on an electronic prescribing system
23	Reis S, 2013	The impact of residents' training in Electronic Medical Record (EMR) use on their competence: report of a pragmatic trial.	Medline CINAHL	Comparative study	Israel	Lack of focus on training and competency on an electronic prescribing system
24	Schenarts PJ, 2012	Educational impact of the electronic medical record [Review]	Medline	Literature Review	UK	Lack of focus on training and competency on an electronic prescribing system

25	Schifferdecker KE, 2012	Adoption of computer-assisted learning in medical education: the educators' perspective.	Medline	Mixed Methods	UK	Lack of relevance for qualified prescribers
26	Baillie L, 2013	A survey of student nurses' and midwives' experiences of learning to use electronic health record systems in practice.	CINAHL	Quantitative (questionnaires) and Qualitative (focus group)	UK	Non-prescribers Undergraduate level
27	Ornes LL, 2007	Computer competencies in a BSN program	CINAHL	Report of curriculum evaluation	US	Lack of qualified, prescriber relevance
28	Liaw, ST 2000	Computer education: don't forget the older GPs.	CINAHL	Quantitative evaluation	Australia	Primary care
29	Wong B, 2012	Computerised provider order entry and residency education in an academic medical centre.	CINAHL	Qualitative	Canada	Lack of focus on training and competency on an electronic prescribing system
30	Sanchez-Mendiola M, 2013	Development and implementation of a biomedical informatics course for medical students: challenges of a large-scale blended-learning program.	CINAHL	Curriculum development	Mexico	Lack of focus on training and competency on an electronic prescribing system
31	Warboys I, 2014	Electronic Medical Records in Clinical Teaching	CINAHL	Evaluation	US	Lack of relevance to qualified prescriber training
32	Shachak A, 2012	End-user support for a primary care electronic medical record; a qualitative case study of a vendor's perspective	CINAHL	Qualitative	Canada	Primary care setting
33	Byrne MD, 2012	Informatics Competence in the EHR Era… 'electronic health record'.	CINAHL	Opinion piece	US	Lack of qualified prescriber training relevance
34	Hart MD, 2008	Informatics competency and development within the US nursing population workforce: a systematic literature review	CINAHL	Systematic Review	US	Lack of relevance for training of qualified prescribers
35	Price D, 2009	Interprofessional education in academic family medicine teaching units: a functional program and culture	CINAHL	Report on interprofessional practice experience	Canada	Lack of prescriber training/ relevance. Primary care setting

36	Turner MP, 2010	Stratifying computer literacy; a competency measurement strategy	CINAHL	Report	US	Lack of relevance to prescriber training
37	Gomes AW, 2013	Strengthening Our Collaborations: Building an Electronic Health Record Educational Module	CINAHL	Report of module development	US	Lack of relevance to qualified prescribers
38	Kassum D, 2009	Targeting adoption, training and device deployment strategies.	CINAHL	Quantitative evaluation	US	Lack of qualified prescriber training relevance
39	Robertson, M, 2003	The education needs of health information managers in an electronic environment: what information technology and health informatics skills and knowledge are required.	CINAHL	Quantitative	Australia	Lack of qualified prescriber training relevance
40	Janssen DG, 2011	The effect of nursing leadership and teaching methodologies on the level of adoption on an electronic health record (EHR) implementation	CINAHL	Quantitative	US	Lack of qualified prescriber training relevance
41	Schumacher D, 2010	The electronic medical record and clinical nursing student instruction: tips and tricks for success.	CINAHL	Report of challenges when educating nursing student and faculty about updates to the EMR.	US	Lack of qualified prescriber training relevance.
42	Aleem S, 2013	Translating 10 Lessons from Lean Six Sigma Project in Paper-Based Training Site to Electronic Health Record-Based Primary Care Practice: Challenges and Opportunities.	CINAHL	Project Report	US	Lack of qualified prescriber training/relevance Primary Care
43	Ulicny MP, 2011	Using an Electronic Health Record in an Introduction to Professional Nursing Course	CINAHL	Abstract of nurse training approach.	US	Lack of qualified doctor/ prescriber training relevance
44	Wolf MS, 2013	Shifting upstream: Efficacy trial of a low literacy, EMR medication education strategy.	Embase	Conference	US	Lack of prescriber training relevance
Publications excluded after review of full text						

45	Maxwell S, 2012	e-Learning initiatives to support prescribing.	Embase	Review	UK	Lack of focus on training and competency on an electronic prescribing system
46	Tierney MJ, 2013	Medical education in the electronic medical record (EMR) era: benefits, challenges, and future directions.	Medline	Perspective piece	US	Lack of focus on training and competency on an electronic prescribing system
47	Ellaway RH, 2013	Medical education in an electronic health record-mediated world.	Medline	Thematic analysis	Canada	Lack of focus on training and competency on an electronic prescribing system
48	Pattillo R, 2010	Cleveland Clinic leads the way in electronic medical record training	CINAHL	Issue Brief	US	Lack of qualified doctor/ prescriber relevance
49	Hoyt R, 2013	Evaluating the Usability of a Free Electronic Health Record Training	CINAHL	Quantitative and Qualitative	US	Lack of qualified prescriber training relevance
50	Edwards G, 2012	Innovative health information technology training: exploring blended learning.	CINAHL	Mixed Methods	US	Lack of prescriber training relevance
51	Laramee A, 2011	Learning from within to ensure a successful implementation of an electronic health record.	CINAHL	Qualitative	Canada	Lack of focus on training and competency on an electronic prescribing system (Not clear if EHR included electronic prescribing)
52	McCain CL, 2008	The right mix to support electronic medical record training: classroom computer-based training and blended learning.	CINAHL	Lessons learnt from training strategy	US	Lack of focus on training and competency on an electronic prescribing system (not clear if EHR includes electronic prescribing)

Publications included after review of full text

53	Kushniruk AW, 209	Bringing electronic patient records into health professional education: towards an integrative framework.	Medline	Educational tool development	Canada	
54	Ayoub N, 2014	Developing competency through webinar to establish oncology pharmacy services at the Aga Khan Hospital Dar-es-Salaam Tanzania.	Embase	Conference; training service development	Pakistan; Tanzania	

55	Foster S, 2011	Competency based training program for electronic prescribing improves patient safety.	Embase	Evaluation of training program (Conference Abstract)	UK
56	Borycki EM, 2009	The University of Victoria Interdisciplinary Electronic Health Record Educational Portal.	Medline	Development of educational portal for EHRs	Canada
57	Bredfeldt CE, 2013	Training providers: beyond the basics of Electronic health records.	Medline	Mixed methods	US
58	Jimenez, A 2010	E-learning supports EHR implementations. In addition to meaningful use, we need to define meaningful training	Review of References	Viewpoint	US
59	Ross C, 2007	The key to CPOE: thoughtful planning, flexible training and strong staff involvement leads to a successful CPOE implementation.	CINAHL	Case history of implementation	US

Articles included and excluded following review of abstract: Online Training

Number	Paper (Author, Year)	Title	Database	Study Type	Country	Justification for exclusion
Publications excluded after review of abstracts						
1	McCullagh P, 2001	Student-centered distance learning in health and medical informatics	Embase	Conference Poster	UK	Lack of focus on training and competency on an electronic prescribing system
2	Masic I, 2013	The history and new trends of medical informatics	Embase	Review	Bosnia and Herzegovina	Lack of focus on training and competency on an electronic prescribing system
3	McGuire MJ, 2013	Evolution of an internet-based quality focused medical education process in an ambulatory care organization	Embase	Conference Abstract	US	Lack of focus on training and competency on an electronic prescribing system
4	Welton N, 2010	The University of Washington electronic medical record experience.	CINAHL	US	Report on development of educational resources.	Lack of qualified prescriber training relevance
Publications excluded after review of full text						
5	McKinney M, 2012 (NB No abstract, must review full text)	Docs helping docs embrace IT; organization uses online tools to promote value of the technology	Medline	Project Report	US	Lack of prescriber training/ competence relevance
6	Topaz M, 2013	Educating clinicians on new elements incorporated into the electronic health record; theories, evidence and one educational project	Medline	Training program development	US	Lack of focus on training and competency on an electronic prescribing system
Publications included after review of full text						
7	Borycki EM, 2009	From prototype to production: lessons learned from the evolution of an EHR educational portal	Medline	Development of educational portal for EHRs	Canada	Yes
8	Jimenez A, 2010	E-learning supports EHR implementations. In addition to meaningful use, we need to define meaningful training	Medline	Viewpoint	US	Yes

| 9 | Ayoub N, 2014 | Developing competency through webinar to establish oncology pharmacy services at the Aga Khan Hospital Dar –es-Salaam Tanzania | Embase | Conference; training service development | Pakistan; Tanzania | Yes |

Appendix 12: Main study observation schedule

Observation Schedule

Participant Reference Number:

Profession of participant:

Consent form signed:

Pre-visit tasks:

Contact key informant day before scheduled observation to remind them of visit and confirm time and place to meet.

Day of observation

1. **Researcher introduces self and thanks participant for agreeing to take part in the study.**

'Hello. It is very nice to meet you. I am Clare Brown, a PhD student at Durham University, currently carrying out research in collaboration with Newcastle Upon Tyne Hospital. I want to thank you very much for agreeing to take part in this study, we are very grateful for your time.'

2. **Brief overview of study aims and explains that the electronic prescribing system is available to demonstrate what they mean.**

'I am investigating the effectiveness of electronic prescribing systems from the point of view of those that use the systems. In order to do this I will observe you today using the system. This information will be used in order to develop systems that work better for you and your colleagues. Do you have any questions about this so far?'

3. **Obtain consent to continue**

'If you are still happy and would like to take part in the study I would be grateful if you could complete the consent form here?'

4. **Confirm information discussed will be anonymised and participant may withdraw themselves and any data from the study at any time.**

'I would like to emphasise that any notes I take will be completely anonymous as will be our conversations. You can choose to withdraw from the study at any time, including after I have observed you.'

5. **Explain will take notes**

You might notice that I am jotting down things as you work. This will be used as a prompt for me later when writing up my findings. I will not record anything that is identifiable and you may see the results of my findings if you wish.

6. **Any further questions?**

Do you have any further questions? If you are happy I will take a step back now and allow you to carry on.

7. **Observations Template**

1. What tasks are being carried out by individual clinicians who use the EP system?

2. What problems do clinicians encounter with the EP system?

3. What contributed to problems?

4. How do clinicians overcome such problems?

8. **Ending the session**

"Thank you very much for allowing me to observe you today. I appreciate your time and if you would like to contact me in the future about this work or if you have any concerns you may email me.

Appendix 13: Main study NHS ethics approval

NHS
Health Research Authority

NRES Committee North East - Sunderland
Room 002
TEDCO Business Centre
Viking Business Park
Jarrow
Tyne & Wear
NE32 3DT

Telephone: 0191 4283564

31 March 2014

Dr Sarah Patricia Slight
Senior Lecturer in Pharmacy Practice
Durham University
School of Medicine, Pharmacy and Health,
Wolfson Research Institute
Queen's Campus, University Boulevard,
TS17 6BH

Dear Dr Slight

Study title:	An evaluation of the impact of an Electronic Prescribing System in one U.K. Hospital Trust
REC reference:	14/NE/0072
Protocol number:	1
IRAS project ID:	141106

The Research Ethics Committee reviewed the above application at the meeting held on 24 March 2014.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details, unless you expressly withhold permission to do so. Publication will be no earlier than three months from the date of this favourable opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to withhold permission to publish, please contact the REC Manager Miss Kathryn Murray, nrescommittee.northeast-sunderland@nhs.net .

Ethical opinion: Favourable Opinion with Conditions

The Chair, Mr Paddy Stevenson, welcomed Mr Neil Watson, a named key investigator of the study team, to the Committee meeting.

The Committee noted that they had no direct questions to ask regarding the study and were happy with the application.

Mr Watson advised that he also had no questions to ask of the Committee.

A Research Ethics Committee established by the Health Research Authority

The Chair thanked Mr Watson for attending the meeting.

The members of the Committee present gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Ethical review of research sites

NHS Sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

1. Submit a revised participant information sheet to include the following:

    - Within the section entitled 'Who has reviewed the study?' include the following additional sentence: 'This study has also been approved by the NRES North East - Sunderland Research Ethics Committee.'

You should notify the REC in writing once all conditions have been met (except for site approvals from host organisations) and provide copies of any revised documentation with updated version numbers. The REC will acknowledge receipt and provide a final list of the approved documentation for the study, which can be made available to host organisations to facilitate their permission for the study. Failure to provide the final versions to the REC may cause delay in obtaining permissions.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements.

Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publicly accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Covering Letter		03 February 2014
Evidence of insurance or indemnity	UMAL	11 July 2013
Interview Schedules/Topic Guides	1	23 January 2014
Investigator CV	Dr Sarah Slight	
Letter from Sponsor		06 January 2014
Letter from Statistician		17 October 2013
Letter of invitation to participant	2	12 December 2013
Other: Data Collection Form 1	2.0	07 December 2013
Other: Data Collection Form 2	1.0	23 January 2014
Other: Data Collection Form 3	2	07 December 2013
Participant Consent Form	2	07 December 2013
Participant Information Sheet	3	16 December 2013
Protocol	3.0	16 December 2013
REC application	141106/559489/1/699	03 February 2014

Membership of the Committee

The members of the Ethics Committee who were present at the meeting are listed on the attached sheet.

The Chair noted that he has given advice to the researchers with regard to ethical issues in this

study.

The Committee discussed and decided that the Chair could remain involved in discussion.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

Further information is available at National Research Ethics Service website > After Review

14/NE/0072	**Please quote this number on all correspondence**

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

Yours sincerely
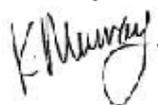
pp.
Mr Paddy Stevenson
Chair

Email: nrescommittee.northeast-sunderland@nhs.net

Enclosures: List of names and professions of members who were present at the meeting and those who submitted written comments "After ethical review – guidance for researchers" [SL-AR2]

Copy to: Dr. Russell Hill, Durham University
Mr Sean Scott, Newcastle Hospitals NHS Foundation Trust
NIGB Ethics & Confidentiality Committee Secretariat

A Research Ethics Committee established by the Health Research Authority

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Appendix 14: Main study Durham University ethics approval

Durham University
School of Medicine,
Pharmacy and Health

Shaped by the past, creating the future

Rebecca Maier
Research, Development and Trials Manager
Chair, School of Medicine, Pharmacy and Health Ethics Sub-Committee

Dr Sarah Slight
School of Medicine, Pharmacy and Health
Durham University

20th December 2013

Dear Sarah,

Re: Ethics Application ESC2/2013/22
An Evaluation of the Impact of an Electronic Prescribing System in one UK Hospital Trust

Thank you for sending the above application to the School of Medicine, Pharmacy and Health Ethics Committee for ethical review. The project was reviewed at a committee meeting on 20th November 2013. The committee requested some changes to the application, and two members of the committee have now reviewed these. We are satisfied that all of the comments made by the committee at the meeting have been adequately addressed and I can therefore confirm Durham University ethical approval for the study.

Approval is given subject to the following:

- That no personal or research data will leave the UK as part of this study

- That a clear statement is added to the protocol describing your intention, or otherwise, to name the NHS Trust in publications. The School sub-committee agree that plans for publication should be reviewed and agreed by the R&D department at the Trust.

- That you gain all relevant NHS REC, governance and Caldicott Guardian approvals prior to starting the research.

- That data generated for this study is maintained and destroyed as outlined in this proposal and in keeping with the Data Protection Act.

- If you make any amendments to your study, these must be approved by the School committee prior to implementation.

- At the end of the study, please submit a short end of study report (ESC3 form) to the School ethics committee.

Please do not hesitate to contact me should you have any questions.

Regards,

Rebecca Maier

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Appendix 15: Main study participant invitation letter

Clare Brown MPharm
School of Medicine, Pharmacy and Health,
Wolfson Research Institute,
Durham University,
Queen's Campus University Boulevard,
Stockton-on-Tees, TS17 6BH, UK
Tel: +44 191 334 0548
Fax: +44 191 334 0374
email: c.l.brown@durham.ac.uk

{Date}

Dear Participant (name)

Study Title: An evaluation of the impact of an electronic prescribing system in a U.K. Hospital Trust

Newcastle Hospitals NHS Foundation Trust in collaboration with Durham University are currently conducting a study to explore staff experiences of using the electronic prescribing system recently implemented in the Trust.

We would like to hear your thoughts on using the system and how it could be improved. We hope that being part of this study will not only provide useful feedback to the research team but also help improve the electronic prescribing system throughout the hospital.

Please find enclosed an information sheet that explains the background to the study, and what would be expected of you should you agree to participate. Please email c.l.brown@durham.ac.uk indicating whether or not you would be interested in participating. It is up to you to decide whether or not to take part. If you decide to take part, you are still free to withdraw at any time in the future. All information supplied is treated in confidence. Thank you for your consideration. If you have any questions regarding this study or require further information, please do not hesitate to contact me by e-mail or on the telephone number above.

Yours sincerely,

Miss Clare Brown
PhD Student, Durham University,

Dr. Sarah Patricia Slight,
Senior Lecturer in Pharmacy Practice, Durham University,
Chief Investigator,

Mr. Neil Watson,
Director of Pharmacy and Medicine Management,
Principal Investigator at Newcastle Hospitals Research Site

Appendix 16: Main study participant information sheet

Study Title: An evaluation of the impact of an electronic prescribing system in a U.K.

Hospital Trust

Participant Information Sheet

Names of Investigators: **Dr. Sarah Patricia Slight, Miss. Clare Brown, Mr. Neil Watson, Mr. Andrew Heed**

Invitation paragraph

You have been invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. If there is anything that is unclear or if you would like more information, please ask. Thank you for reading this.

Background

The introduction of an electronic prescribing system can increase the likelihood of preventing medication-related errors. Computerised tools can eliminate illegible orders, provide dosing suggestions, assist with calculations and monitoring, and improve compliance with preventive service protocols. However, the use of an electronic prescribing system can also promote medication error risks in addition to reducing them. Examples included fragmented computer screen displays that prevented a coherent view of patients' medications, failure to differentiate between look-alike drug names, and inflexible ordering formats generating wrong medication orders. Reducing the risks of iatrogenic harm is a key issue for the NHS.

The aim of this study is to explore your views and experiences of the different design features of the electronic prescribing system.

What does the study involve?

This study explores the electronic prescribing system and its many different dimensions currently in use at Newcastle Hospitals NHS Foundation Trust. We would like to hear your thoughts on using the system and how it could possibly be improved.

Why have I been chosen to take part?

Your ward has recently implemented or is currently implementing an electronic prescribing system, and you have been chosen because you may be able to provide useful feedback on the use of various elements of this system.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part, you will be given this information sheet to keep and will be asked to sign and return the consent form. You are also free to withdraw at any time and without giving a reason.

What do I have to do?

By agreeing to take part, you may be required to participate in an interview. This interview will be

conducted by a member of our research team at a mutually convenient time and place, and will take approximately 30-40 minutes. We would like to explore your experiences of using the electronic prescribing system and how the system could be further improved. If you agree, the interview will be digitally recorded; if you object to this, however, we will just take notes. You can ask that the digital recorder be switched off at any time during the interview if you prefer.

What if something goes wrong? / Who can I complain to?

In case you have a complaint on your treatment by a member of research staff or anything to do with the study, you can approach the chief investigator, **Dr. Sarah Patricia Slight**, School of Medicine, Pharmacy and Health, Wolfson Research Institute, Durham University, Queen's Campus, University Boulevard, Thornaby, Stockton-on-Tees, TS17 6BH. Phone: +44 (0191) 334 0548. Email: s.p.slight@durham.ac.uk. Independent advice can also be sought from Newcastle Trust's R&D Department. Phone +44 (0191) 282 5959 or E-mail: trust.r&d@nuth.nhs.uk

Will my taking part in this study be kept confidential?

All information supplied will be kept confidential. Any information reported from the interview will not enable you to be recognised. You will not automatically be expected to take part in any future research. All information, which is collected about you during the course of the research, will be kept on a password-protected database and held securely in accordance with the regulations. Access to the information will be limited to the study staff and investigators only. Any personal data will be destroyed as soon as is practical and reasonable to do so (approx. 4 weeks after the date of interview). Any information about you, which leaves the research unit, will have your name and address removed so that you cannot be recognised from it.

What will happen to the results of the research study?

We plan to submit the findings of this study to medical journals (papers) for publication. You will not be identified in any report/publication.

Who is organising and funding the research?

This study is part of research funded by the Durham University.

Who has reviewed the study?

This study has been reviewed and approved by the SMPH Ethics Committee Durham University.

Contact for Further Information

Miss. Clare Brown, School of Medicine, Pharmacy and Health, Wolfson Research Institute, Durham University, Queen's Campus, University Boulevard, Thornaby, Stockton-on-Tees, TS17 6BH. Phone: +44 (0191) 334 0548. Email: c.l.brown@durham.ac.uk **Dr. Sarah Patricia Slight,** School of Medicine, Pharmacy and Health, Wolfson Research Institute, Durham University, Queen's Campus, University Boulevard, Thornaby, Stockton-on-Tees, TS17 6BH. Email: s.p.slight@durham.ac.uk. **Mr. Andrew Heed,** Lead Clinical Informatics Pharmacist, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Queen Victoria Road, New Victoria Wing, Royal Victoria Infirmary, Newcastle Upon Tyne, NE1 4LP Email: Andrew.Heed@nuth.nhs.uk

Thank you very much for considering taking part in this research study.

Appendix 17: Main study consent form

Study Title: An evaluation of the impact of an electronic prescribing system in a U.K. Hospital Trust

Ethical Approval Ref: *(to be added)*

Name of Researcher: _____

Name of Participant: _____

Please initial box

1. I confirm that I have read and understand the information sheet version number …………dated………… for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason. I understand that should I withdraw then the information collected so far cannot be erased and that this information may still be used in the project analysis.

4. I understand that the interview will be recorded and that anonymous direct quotes from the interview may be used in the study reports.

5. All information supplied will be kept confidential. Any information reported will not enable you to be recognised.

6. I agree to take part in the above study.

_____   _____   _____

Name of Participant   Date   Signature

_____   _____   _____

Name of Person taking consent   Date   Signature

2 copies: 1 for participant and 1 for the project notes

Appendix 18: Main study participant interview schedule

Study Title: An evaluation of the impact of an electronic prescribing system in a U.K.

Hospital Trust

Participant Interview Schedule

A common introduction will be used as follows:

In this interview and, as a member of ward staff in this hospital, we would like to gain your impressions of using the electronic prescribing system. We are interested in your opinions whether these are positive or negative. If there are any questions you do not feel you can answer, we can easily skip over that question.

QUESTIONS

1. *What are your experiences of using the system?*

Prompt: What were your likes and dislikes?

2. *How has the system been tailored to your individual needs?*

Prompt: What is most useful? Not so useful?

3. *What do you find difficult about using the system?*

Prompt: Difficulty placing orders, receiving lab results, finding particular information?

4. *Have you or your colleagues developed "short-cuts" to enable you to get around these difficulties?*

5. *How do you think this electronic system could be improved?*

6. *Do you have any other comments?*

Concluding remarks will end the interview:

That was the last question on this interview. As I mentioned earlier, all data are stored anonymously and you will not be identifiable from any uses of these data. If you would like any further information about the study, please don't hesitate to contact me. My details have been provided on the information sheet.

Thank you for taking part in this interview.

Appendix 19: Ethical approval for training study

Durham University
School of Medicine,
Pharmacy and Health

Shaped by the past, creating the future

Dr Shelina Visram
Lecturer, Centre for Public Policy and Health
Deputy Chair, School of Medicine, Pharmacy and Health Ethics Sub-Committee

Sarah Slight
School of Medicine, Pharmacy and Health
Durham University

10th August 2015

Dear Sarah,

Re: Ethics Application ESC2/2015/12
Electronic prescribing systems and the training offered to newly employed prescribers.

Thank you for sending the above application to the School of Medicine, Pharmacy and Health Ethics Sub-Committee for ethical review. The project was reviewed at a meeting on 22nd July 2015. The committee requested some changes to the application, and I have now reviewed these as Deputy Chair. I am satisfied that all of the comments made by the committee have been addressed and I am therefore pleased to confirm Durham University ethical approval for the study.

This approval is given on the following basis:

- Please ensure that data generated for this study is maintained and destroyed as outlined in this proposal and in keeping with the Data Protection Act.

- If you make any amendments to your study, these must be approved by the School committee prior to implementation.

- At the end of the study, please submit a short end of study report (ESC3 form) to the School ethics committee.

Please do not hesitate to contact me should you have any questions. Good luck, I hope that the study goes well.

With best wishes,

Shelina Visram

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Appendix 20: The follow-on study participant interview schedule

Study Title: Electronic prescribing systems and the training offered to newly employed prescribers.

Participant Interview Schedule

A common introduction will be used as follows:

In this interview, we would like to hear about the types of training offered to newly employed prescribers in using the electronic prescribing system at your trust and any particular lessons learnt. We are interested in what you felt went well and perhaps did not go so well. If there are any questions you do not feel you can answer, we can easily skip over that question.

Before we begin it is important that I have an audio-record of your consent to take part in this interview, could you please answer the following questions:

1. *Can you please confirm that you have read and understand the information sheet for the above study and have had the opportunity to ask questions?*
2. *Do you understand that your participation is voluntary and that you are free to withdraw at any time, without giving any reason? Do you understand that should you withdraw then the information collected so far cannot be erased and that this information may still be used in the project analysis?*
3. *Do you understand that the interview will be recorded and that anonymous direct quotes from the interview may be used in the study reports?*
4. *Do you understand that all information supplied will be kept confidential? Any information reported will not enable you to be recognised.*
5. *Finally, do you agree to take part in the above study?*
6. *Do you have any questions before we begin?*

QUESTIONS

1. What types of training and support are offered to staff?

   Prompt: classroom based sessions, on-line training approaches?

2. Is the training offered and supported by the companies that install the systems? If not, who provides or designs the training?

3. How is the training facilitated?

   Prompt: Who conducts the training at the site? What are staff asked to do as part of their training? What scenarios do they work through?

4. What parts of the training went well or not so well in your opinion?

   Prompt: Low staff attendance? Online convenient for staff?

5. What lessons have been learnt from the training already provided?

   Prompt: More trainers required? Increased technical support needed?

6. What are the resources and cost associated with the training?

   Prompt: Number of trainers required? Number of sessions provided to each member of staff? Length of each session? Time required to develop the training material?

Concluding remarks will end the interview

That was the last question on this interview. As I mentioned earlier, all data are stored anonymously and you will not be identifiable for any uses of these data. If you would like any further information about the study, please don't hesitate to contact me. My details have been provided on the information sheet.

Thanks you for taking part in this interview.