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Accounting, Finance & Information Systems

The Framework for REVIEWS:
An Exploration into Design Principles for an Electronic Medical Early Warning System Observation Chart

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Thesis Submitted to the National University of Ireland, Cork for the Degree of Doctor of Philosophy

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April 2016

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The Author declares that, except where duly acknowledged, this thesis is entirely his own work and has not been submitted for any degree in the National University of Ireland or any other University.

DEDICATIONS

Woods on a Snowy Evening

Whose woods these are I think I know.
His house is in the village though;
He will not see me stopping here
To watch his woods fill up with snow.

My little horse must think it queer
To stop without a farmhouse near
Between the woods and frozen lake
The darkest evening of the year.

He gives his harness bells a shake
To ask if there is some mistake.
The only other sound's the sweep
Of easy wind and downy flake.

The woods are lovely, dark and deep,
But I have promises to keep,
And miles to go before I sleep,
And miles to go before I sleep.

Dedicated to the memory of my Dad
Dr Con Don Creedon
Here's to having values bigger than ourselves and savouring the minutiae.

Dedicated to the constant love, warmth and support of my Mam
Mrs Freda Creedon
Here's to surrounding ourselves with art, nature, family and hilarity.

Dedicated to the supernatural awesomeness of my future wife
Ms Aoife McCarthy
Here's to absolute devotion to the ones we love and maintaining all of the above…

ABSTRACT

The observation chart is for many health professionals (HPs) the primary source of objective information relating to the health of a patient. Information Systems (IS) research has demonstrated the positive impact of good interface design on decision making and it is logical that good observation chart design can positively impact healthcare decision making. Despite the potential for good observation chart design, there is a paucity of observation chart design literature, with the primary source of literature leveraging Human Computer Interaction (HCI) literature to design better charts. While this approach has been successful, this design approach introduces a gap between understanding of the tasks performed by HPs when using charts and the design features implemented in the chart. Good IS allow for the collection and manipulation of data so that it can be presented in a timely manner that support specific tasks. Good interface design should therefore consider the specific tasks being performed prior to designing the interface.

This research adopts a Design Science Research (DSR) approach to formalise a framework of design principles that incorporates knowledge of the tasks performed by HPs when using observation charts and knowledge pertaining to visual representations of data and semiology of graphics. This research is presented in three phases, the initial two phases seek to discover and formalise design knowledge embedded in two situated observation charts: the paper-based NEWS chart developed by the Health Service Executive in Ireland and the electronically generated eNEWS chart developed by the Health Information Systems Research Centre in University College Cork. A comparative evaluation of each chart is also presented in the respective phases. Throughout each of these phases, tentative versions of a design framework for electronic vital sign observation charts are presented, with each subsequent iteration of the framework (versions Alpha, Beta, V0.1 and V1.0) representing a refinement of the design knowledge. The design framework will be named the framework for the Retrospective Evaluation of Vital Sign Information from Early Warning Systems (REVIEWS). Phase 3 of the research presents the deductive process for designing and implementing V0.1 of the

framework, with evaluation of the instantiation allowing for the final iteration V1.0 of the framework.

This study makes a number of contributions to academic research. First the research demonstrates that the cognitive tasks performed by nurses during clinical reasoning can be supported through good observation chart design. Secondly the research establishes the utility of electronic vital sign observation charts in terms of supporting the cognitive tasks performed by nurses during clinical reasoning. Third the framework for REVIEWS represents a comprehensive set of design principles which if applied to chart design will improve the usefulness of the chart in terms of supporting clinical reasoning. Fourth the electronic observation chart that emerges from this research is demonstrated to be significantly more useful than previously designed charts and represents a significant contribution to practice. Finally the research presents a research design that employs a combination of inductive and deductive design activities to iterate on the design of situated artefacts.

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For me, this thesis represents the culmination of a long held ambition. This ambition could not have been fulfilled had it not been for the help, patience, kindness, guidance, friendship and love of a number of groups and individuals.

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I would like to thank the staff of the BIS department in UCC. Throughout the past 4 years working in the department I have come to know staff who previously lectured me in a different light. I have come to know a group of funny, kind and hardworking people. I thank all staff who have given me advice regarding my PhD and those that have helped to guide me with my own lecturing endeavours. In particular I would like to thank Professor Ciaran Murphy for providing the opportunity for me to conduct my PhD research and to teach.

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I would like to thank my colleagues who have shared room 2.110 with me. If the supporters at a soccer game are the twelfth man, then these people have been my fourth supervisor. Countless early morning discussions regarding metaphysics,

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I would like to thank all members of staff of Nenagh General Hospital who contributed towards the research process. This was a relationship set in stone prior to me entering the research project thanks in large part to the vision of Dr John Kellett. Dr Kellett's passion for improving healthcare was inspiring to behold, his passion for the research project buoyed the project during time of times of uncertainty. I would like to thank members of management in Nenagh General Hospital for facilitating trials and organising interviews. In particular I would like to thank the staff in the Medical Assessment Unit (MAU). I was lucky enough to be able to set up camp in the MAU ward during my data collection phases and the staff could not have been kinder or more insightful.

I would like to thank the Science Foundation Ireland for providing funding for the research project and the studentship that was provided to me as part of the funding.

I would like to thank my friends, especially those who have spotted me a pint or two whenever funds were short. Next round is on me.

Finally, I would like to thank my family and my future wife. You have all provided a haven from sometimes choppy waters and remain my greatest inspiration.

Chapter 1 : INTRODUCTION

1. Chapter Overview

The purpose of this chapter is to present a high level overview of the research topic and the motivation for the research. The chapter will begin with a brief discussion of clinical reasoning and will discuss how Information Systems research can be adopted to provide support for clinical reasoning.

In order to situate this study, the case study on which this research will be grounded is also presented. Furthermore, this chapter will present an overview of the structure of the thesis, the principal contributions that will emerge from the research, as well as the published findings from the study.

1.1. Motivation for this Research

Good clinical reasoning (CR) is an essential skill for any nurse to possess in order for them to be able to identify patients at risk of deterioration (Banning, 2008a). As such, clinical reasoning and in particular the teaching of clinical reasoning skills has been subject to significant academic attention in nursing studies (Dickson & Flynn, 2012; Fonteyn & Grobe, 1992; Lapkin, Levett-jones, Bellchambers, & Fernandez, 2010; Tanner, 2006).

A number of definitions exist for CR, with some definitions concentrating on the decision-making element of CR, with others positing that CR is concerned with clinical judgement (Tanner, 2006). In an effort to synthesise the CR literature, Levett-Jones et al., (2010), developed a high level process model for CR that reflects the different cognitive tasks performed by nurses during clinical reasoning. This model is defined as *the clinical reasoning process*, the model contains 8 phases, with each phase consisting of specific cognitive tasks.

Phase of the Clinical Reasoning Process	Tasks Performed During Each Stage
1. *Consider the Patient Situation*	Describe or list facts, context, objects or people.
2. *Collect Cues/Information*	Review current information. Gather new information. Recall knowledge.
3. *Process Information*	Interpret: Analyse data to come to an understanding of signs or symptoms. Compare normal V abnormal. Discriminate: Distinguish relevant from irrelevant information, recognise inconsistencies, narrow down the information to what is most important and recognise gaps in cues collected. Relate: Discover new relationships or patterns; cluster cues together to identify relationships between them. Infer: Make deductions or form opinions that follow logically by interpreting subjective and objective cues; consider alternatives and consequences. Match: Current situations to past situations or current patients to past patients (usually an expert thought process). Predict: an outcome (usually an expert thought process).
4. *Identify Problems/Iissues*	Synthesise facts and inferences to make a definitive diagnosis of the patient's problem.
5. *Establish Goals*	Describe what you want to happen, a desired outcome, a time frame.
6. *Take Action*	Select a course of action between different alternatives available.
7. *Evaluate Outcomes*	Evaluate the effectiveness of and actions outcomes. Ask: "has the situation improved now?"
8. *Reflect on Process and New Learning*	Contemplate what you have learnt from this process and what you could have done differently.

Table 1.1. Tasks performed during the clinical reasoning process.

Table 1.1 presents the phases of the clinical reasoning process and demonstrates the cognitive tasks conducted by nurses during the process of clinical reasoning. The process of performing these cognitive tasks allows nurses to make good or bad care decisions for a patient. Many of these tasks require the nurse to use vital sign data about the patient and contextual information about the patient to make these

decisions. Considering the important role information plays in allowing the nurse to make care decisions for a patient, it is reasonable to posit that tackling the subject of clinical reasoning from an information systems perspective can yield useful results.

It is therefore logical to state that the quality of the data presented and the quality of how the data is presented will affect the ability of a nurse to make care decisions for a patient. That is to say that superior design of the interface for presenting patient health data can lead to improvements in nurse performance (Christofidis, Hill, Horswill, & Watson, 2013).

When considering the design of interfaces for presenting data, it is useful to turn to Information Systems research to identify theoretical knowledge that can contribute to improved design. Information systems research has a tradition of studying the cognitive tasks associated with decision making and additionally has a tradition of designing information systems that can help to support decision making (Delaney, Fitzmaurice, Riaz, & Hobbs, 1999; G. A. Klein & Klinger, 1991; Simon et al., 1987). Furthermore, there is an mature research agenda to develop health information systems that can have a positive impact on the decision making of health practitioners (Delaney et al., 1999; Kawamoto, Houlihan, Balas, & Lobach, 2005; Prytherch, Smith, Schmidt, & Featherstone, 2010). While it is reasonable to state that information systems have the potential to support the clinical reasoning process and clinical decision making, it is useful to first consider the clinical reasoning process from an information systems perspective.

1.1.1. An Information Systems Perspective

Information systems (IS) research has yielded useful insights through the application of theoretical knowledge for practical benefit in relevant disciplines. This can be seen in the strong presence of information systems theory in the decision making, financial management and healthcare disciplines (Agarwal & Lucas, 2005; Yoo, 2010). In the case of this research project, this research will investigate how information systems theory can be applied to benefit the practice of clinical reasoning (CR) when performed by nurses. Prior to establishing why studying clinical reasoning support from an IS perspective is useful; there is first a necessity to identify the areas of overlap in the two phenomena. In order to do this

there is a necessity to present a definition for information systems. The focal point for IS research has been much debated within the IS academic community (Agarwal & Lucas, 2005; I. Benbasat & Zmud, 2003). This debate does not necessarily revolve around what the definition of information is, but is concerned with what the boundaries of what IS research should be. While identifying a universally accepted definition of an information system is difficult, Galliers (2003) seeks to come to an understanding of the definition of information systems by first discussing what information is and then asserting what the boundaries of an information system are. Galliers (1987) defines information as:

> *... that collection of data, which, when presented in a particular manner and at an appropriate time, improves the knowledge of the person receiving it in such a way that he/she is better able to undertake a [required] activity or make a [required] decision.*

With Scholes & Checkland (1990) defining the boundaries of an information system as including the *attribution of meaning… data manipulation* [done by machines]... *and the transformation of data into information* [done by humans]... and that designing an information system *will require explicit attention to the purposeful action* to which it serves (R. Galliers, 1987).

From these definitions of information and the boundaries of an information system, we can observe that there are essentially four basic requirements for an information system. These are:

1. Collect data.
2. Manipulate data.
3. Present data in a particular manner, in a timely way.
4. Information serves a specific function.

If we consider the phases of the clinical reasoning process, we can see that a number of the phases are dependent on the collection and manipulation of raw data as vital signs. For the purpose of demonstrating this, a simple scenario is presented on Table 1.2 where a standardised form that is used to collect and present patient data (the information system) can be used to support the clinical reasoning phase of *consider the patient situation*, as presented in Table 1.1.

Information Systems Requirements	Consider the Patient Situation
Collect data	Collect contextual data about the patient, (vital signs, age, physical condition, etc.)
Manipulate data	Manipulate data to give you an insight into the patient's health. A standardised form gives a basic level of data manipulation, i.e. data can be structured in a logical way to allow a health professional to consider the patient.
Present data in a particular manner, in a timely way	The form should be organised in a way to make logical examination of the patient data possible. Presenting the data in a logical way gives the data context.
Information serves a specific function	Contextual data collected about a patient can be used to allow the health professional to describe or list facts, context, objects or people. This information serves the clinical reasoning phase of *consider the patient situation.*

Table 1.2. Information system requirements for considering a patient situation

The scenario presented in Table 1.2 demonstrates that the task of *consider the patient situation* can be supported by the use of an information system. While this scenario demonstrates how *consider the patient situation* can be supported, it would also be quite simple to present scenarios where information systems could also support the clinical reasoning phases of: *collect cues/information, process information, identify problems/issues and evaluate outcomes.* Each of these phases could be supported by an information system that would collect data, manipulate data, present data in a particular manner, in a timely way and provide information that serves a specific function.

While it is clear that many of the phases of the clinical reasoning process would benefit from the design of an information system, this study will focus on designing an information system that supports the phase of *process information.* Of the clinical reasoning phases described, this phase appears to be the most complex. During this phase the health practitioner must:

- Interpret: Analyse data to come to an understanding of signs or symptoms. Compare normal V abnormal vital sign.

- Discriminate: Distinguish relevant from irrelevant information, recognise inconsistencies, narrow down the information to what is most important and recognise gaps in cues collected.
- Relate: Discover new relationships or patterns; cluster cues together to identify relationships between them.
- Infer: Make deductions or form opinions that follow logically by interpreting subjective and objective cues; consider alternatives and consequences.
- Match: Current situations to past situations or current patients to past patients (usually an expert thought process).
- Predict: an outcome (usually an expert thought process).

While the number of tasks performed during this clinical reasoning phase is higher than the other phases, two of the phases are also described as e*xpert thought processes*. This implies that the tasks of matching situation and making predictions are difficult tasks to master, furthermore this implies that these are desirable skills for an individual to master in order to allow them to better identify patients at risk of deterioration (Fonteyn & Grobe, 1992; K. a Hoffman, Aitken, & Duffield, 2009; Orme & Maggs, 1993).

From a practitioner's perspective, there are clear merits for researching the *process information* phase of clinical reasoning. It is logical that any research that attempts to better understand this complex phenomena, can lead to improvements in how the phenomena can be supported. It therefore follows that better support for *information processing* should lead to improved clinical reasoning and improved patient outcomes. This leads to a question regarding the relevance of information systems research in terms of supporting the information processing phase of clinical reasoning.

1.1.2. A Note on Data, Information and Knowledge

Section 1.1.1 presented a discussion on the relevance of observation chart design to IS research. The fundamental principle being that an observation chart is an information system that can be used to support nurses in reviewing vital sign data that has been organised in a manner which gives meaning to the data. The definition

of an information system presented by R. Galliers, (1987) in section 1.1.1 also suggests that data when presented *in a particular manner and at an appropriate time, improves the knowledge of the person receiving it in such a way that he/she is better able to undertake a [required] activity or make a [required] decision*.

This observation presents an indication as to the relationship between data, information and knowledge. It is important to present an understanding on the relationship as misunderstanding of the relationship can lead to issues in IS design (Davenport & Prusak, 1998, pg. 37). Van der Spek & Spijkervet, (1997) present the following definition of data, information and knowledge

> ***Data*** *are symbols which have not yet been interpreted. We are confronted daily with data in various forms. Examples are a red light on a dashboard or a set of process data in a factory*
>
> ***Information*** *is data which has been assigned a meaning. A chauffeur assigns meaning to the red light and will stop because, according to his interpretation, over-heating has occurred. A graph provides information of the relation between aspects on the horizontal and vertical axis of the graph and shows, e.g., that there is a certain trend. Information is always linked to a specific situation and has only limited validity.*
>
> ***Knowledge*** *is that which enables people to assign a meaning to data and therefore generate information. Knowledge, therefore, enables people to act and to intelligently deal with all the information sources available. A red light on a dashboard can mean low oil level, a low petrol level, or a warning that a brake is not functioning. Knowledge about the car is required to choose the right action or ask for the right information! This action component is an essential aspect of knowledge.*

This definition provides a useful insight into the support an electronic observation chart cab provide to healthcare professionals and also the limits of the system.

Data Vital sign data observed by HCPS can be recorded on the observation chart

Information Using a graph to demonstrate the contextual meaning of vital sign data recordings assigns meaning to the data.

Knowledge HCPs employ their experiential knowledge to act on information presented on the chart.

It can be inferred from the description of data, information and knowledge from an observation chart design perspective as presented above that an observation chart can be useful in transforming data into information, and while an observation chart may be a useful training tool to assist HCPs in acquiring knowledge, it and of itself does not provide the viewer of the chart with knowledge.

1.1.3. The NEWS and eNEWS Charts

In order to conduct this study, an electronic Aggregate Weighted Track and Trigger System (AWTTS) developed by the Health Information Systems Research Centre (HISRC) in University College Cork (UCC) has been identified as an appropriate case study. AWTTS assign scores to a pre-defined set of vital signs in particular ranges, with the aggregate of these scores constituting an *early warning score*. Based on the early warning score calculated, a minimum standard of care for the patient is then set based on the score recorded (G. B. Smith et al., 2008). A key component of the eNEWS system is a vital sign observation chart that has been designed to mimic the look and feel of a vital sign chart developed by the Irish Health Service Executive (HSE) as part of their National Early Warning Score (NEWS) system. These systems are designed to facilitate the recording of basic patient information and vital signs and to display this information on a graphical chart (See appendix 1 for NEWS system instructions).

The Irish HSE began implementing the NEWS system in hospitals in Ireland in 2012. At the time of writing this thesis NEWS has become the standard vital sign chart in many hospitals in Ireland. As such, the NEWS chart plays an important role in the collection and communication of patient data to nurses working within the

Irish HSE. The NEWS chart is likely to be an important tool to support the clinical CR phase of *information processing* for many nurses. The NEWS and eNEWS charts, therefore, represent a good opportunity to perform research for designing an information system that can provide superior support for the CR phase of i*nformation processing*.

The electronic system developed by the HISRC (eNEWS), at the time of the study is still in the development phase and consequently there is the potential to implement any findings from this research which can improve how data is presented in a manner which can facilitate information processing.

Considering the information presented in the chapter the objective of this research can be defined as:

> *To investigate and produce a set of design principles, which when instantiated, have a positive impact on nurses ability to process information presented on an electronically generated vital sign chart. The set of design principles will be referred to as the framework for REVIEWS.*

1.1.4. Ethical Approval for this Research

In order to conduct any research within a healthcare organisation there is a necessity to first acquire ethical approval for the research. The development of the eNEWS chart was conducted as part of a research project pioneered by Dr John Kellett, Consultant Physician of the Mid-Western Regional Hospital under the following protocol title:

Assessment of the impact of a novel predicator instrument of mortality and monitoring technology on the delivery of acute medical care which includes;

- *Simple clinical score.*
- *Several electronic and manual blood pressure machines compared with mercury.*
- *Electronic thermometer compared with mercury.*
- *Non-invasive cardiac monitoring compared with physical examination.*
- *Non-invasive respiratory rate monitoring compared with physical examination.*
- *Non-invasive accelerometer for falls risk monitoring.*

All data collected for this research and presented in this thesis was captured in Nenagh General Hospital as part of this research project. All data collected during the research was anonymous and maintained in accordance to the Data Protections Acts of 1988 and 2003.

1.1.5. Research Funding

The research conducted in order to complete this thesis was funded by Science Foundation Ireland through a New Research Frontiers Programme Grant titled Pervasive Decision Support Systems within a Remote Patient Monitoring Environment (pDSS).

1.2. Thesis Structure

Chapter 2 presents a literature review of literature pertinent to the design of information systems that are designed to help individuals or groups to identify patients at risk of deterioration and complete pre-emptive actions. AWTTS are frequently referred to as early warning systems, due the fact that they are designed to identify early signs of deterioration and prevent emergency situations. As such, this chapter will begin by studying the design of other examples of early warning systems. Based on the knowledge synthesised from this review, the existing AWTTS chart design literature is critically evaluated to establish the strengths and weaknesses of the literature.

Chapter 3 presents the research approach that this research will employ. As the objective of the research is concerned with producing a set of design principles, this research will employ a Design Science Research (DSR) approach. This chapter presents the metaphysic and methodological considerations that employing a DSR approach entail.

Instantiation	Description	Design Artefact
NEWS Chart	By theorising about the problem space and analysing the instantiation to identify design principles, REVIEWS Alpha can be formalised.	REVIEWS Alpha
eNEWS Chart V1.0	eNEWS was designed to mimic the look and feel of NEWS, however, due to the nature of electronic systems and as the chart was in early stages of development there were a number of design differences. These design differences were abstracted and reflected in REVIEWS Beta.	REVIEWS Beta
eNEWS Chart V2.0	Through further theorising and exploring extant literature, the framework for REVIEWS will be further refined. These design principles are then instantiated in eNEWS V2.0 . Some further experimental design features are also developed.	REVIEWS V0.1
Future version of eNEWS Chart	Framework for REVIEWS 0.1 can be formalised. The framework reflects the findings from phase One, Two and Three. REVIEWS V1.0 represent the fourth iteration of the design artefact.	REVIEWS V1.0

Table 1.3. Overview of iterative observation chart refinement.

Chapter 4 presents the development of the first two iterations of the framework for REVIEWS (versions Alpha and Beta). These iterations of the framework represent tentative design frameworks that have been formalised through the use of inductive and empirical data gathering methods. Chapter 4 also presents the methodology for comparative evaluation that this research will employ. The data collection procedure, analysis procedure and comparative evaluations of both the NEWS and eNEWS charts are also presented in chapter 4.

Chapter 5 presents the design knowledge necessary to formalise the third iteration of the framework (V0.1). The design builds on the work of Baker et al., (2009) who hypothesises that aspects of visual representation can support data exploration tasks during the sense making process. Commonalities are identified between data exploration tasks performed during sense making and information processing tasks performed during clinical reasoning. Theories from semiology of graphics literature

are employed to establish design principles for visually presenting patient vital sign data on charts.

Chapter 6 presents a demonstration of how V0.1 of the framework can be instantiated, as well as the comparative evaluation of the new electronic observation chart compared to the paper-based NEWS chart and version 1 of the electronically-generated eNEWS chart.

Chapter 7 presents the process of formalising the fourth iteration of the framework (V1.0). Chapter 7 then presents a discussion regarding the principal contributions from this research. Limitations of the research are discussed. Opportunities for future research are presented. Table 1.5 presents an overview of the knowledge that emerges from chapters 1 to 7.

<table>
<tr><th>Chapter</th><th colspan="2">Focus</th><th>Outcome</th></tr>
<tr><td>1
Introduction</td><td colspan="2">Clinical reasoning is an integral part of healthcare decision making.
Observation charts act as the primary information system for supporting clinical reasoning processes.
Observation charts are necessary to support the information processing phase of the clinical reasoning process.
However, no existing research has formalised design features that supports clinical reasoning
It is logical that an electronic early warning system may serve as a good basis for designing an electronic observation chart that can support information processing.</td><td>Research objective: To investigate and produce a set of design principles, which when instantiated, have a positive impact on nurses ability to process information presented on an electronically generated vital sign charts. The set of principles will be referred to as the framework for REVIEWS.</td></tr>
<tr><td>2
Literature
Review</td><td>Medical Early Warning Systems Lit
The design of a good EWS can be deconstructed into 4 rules:
1) Risk Knowledge
2) Monitoring & Warning Service
3) Dissemination & Communication
4) Response Capability

Medical EWS have a reliance on human information processing

Medical EWS need to be designed to support the human decision maker rather than replace them.</td><td>Observation Chart Design Lit
Employed a 'Human Factors' design approach and Human Computer Interaction design heuristics to establish useful design features.
Existing literature evaluation methods focus on heuristic evaluation and adapting HCI literature to help identify design features that contribute towards improving the speed and accuracy by which nurses an identify abnormal vital signs.

By adopting a design feature-led approach, there is a disconnect between task and theory
This makes iterative design and transparent rigorous evaluation difficult.</td><td>There is a need to implement a design process that is theory-led, is designed to support the human decision maker and in particular can support the information processing phase of clinical reasoning.</td></tr>
</table>

<table>
<tr><th>Chapter</th><th colspan="2">Focus</th><th>Outcome</th></tr>
<tr><td rowspan="6">3
Methodology and Research Design</td><td colspan="2">The objective of this research is concerned with formalising prescriptive design principles that have a positive impact on nurses' ability to process information presented on an electronically generated vital sign chart.
This research will take a design science approach for iterating on situated artefacts.</td><td rowspan="6">The research design will consist of three phases. The initial two phases will retrospectively evaluate the situated paper-based NEWS and electronically generated eNEWS charts. The data gathered from this phase will contribute practical and theoretical knowledge necessary to design the framework for REVIEWS. Phase 3 will take the form of a traditional design-build-evaluate approach to Design, Instantiate and comparatively evaluate the framework for REVIEWS.</td></tr>
<tr><td>Evaluation Method:</td><td>Semi-structured interviews for comparative evaluation of artefacts.</td></tr>
<tr><td>Objects for evaluation:</td><td>Paper-based NEWS chart, electronically generated NEWS chart, eNEWS V2.0 chart with instantiated framework for REVIEWS.</td></tr>
<tr><td>Level of comparison:</td><td>Attributes of each of the observation charts.</td></tr>
<tr><td>Conceptual comprehension:</td><td>Constructs will be explained to interviewees using practical examples.</td></tr>
<tr><td>Analysis of findings:</td><td>Inductive analysis.</td></tr>
</table>

Table 1.4. Structure of thesis chapters 1 to 3.

	Problem Formalisation		*New Design Input*	
	Phase 1 Nov 2013	***Phase 2 Feb 2014***	***Phase 3 Dec 2014***	***End***
Purpose of Design Phase	***Reflect on design and usefulness of the paper-based NEWS chart.***	***Reflect on design and usefulness of the electronic eNEWS V1.0 chart.***	***Introduce deductive design theory development process to help create eNEWS V2.0.***	
Practical and Academic Design Knowledge	**What tasks does the chart support?** **What design features support each task?**	**What can the previous evaluation tell us?** **To what extent do design features support tasks?**	**What can the previous evaluation tell us?** **What theoretical knowledge can be leveraged to improve chart design?** **How can these theories be leveraged?**	**What can the previous evaluation tell us?** **What can the design process tell us?**
Resulting Design Artefact	***Tentative Design Theory*** ***REVIEWS Alpha***	***Tentative Design Theory*** ***REVIEWS Beta***	***REVIEWS V0.1*** ***Consists of 23 Design Principles***	***REVIEWS V1.0*** ***Consists of 24 Design principles***
Comparative Evaluation	**NEWS Vs. Legacy Charts**	**eNEWS V1.0 Vs. NEWS**	**eNEWS V2.0 Vs.** **eNEWS V1.0 Vs.** **NEWS**	

Table 1.5. Structure of research phases 1, 2 and 3.

1.3. Contributions from Research

As noted in section 1.1, the objective of this research is to: *To investigate and produce a set of design principles, which when instantiated, have a positive impact on* nurses *ability to process information presented on an electronically generated vital sign chart. The set of design principles will be referred to as the framework for REVIEWS.* In order to achieve this objective, this research has made a number of contributions to the field of AWTTS chart design, to the Design Science academic literature and has also helped to identify areas of commonality between the academic literature pertaining to Clinical Reasoning and to Information Systems.

The principle contribution of this research will be the framework for REVIEWS. There was a necessity to formalise this framework as literature regarding vital sign chart design was considered to be sub-optimal. The literature described the design of charts as human-centred, however, a review of the literature demonstrates that there is no clear description of the process by which the design features were formulated and the formalised design features appear to have been identified using a design feature-led approach. A design theory-led approach is considered to be optimal with this being discussed in more detail in section 2.3. The design process for this research leverages empirical observation made during the evaluation of the situated NEWS and eNEWS charts, as well as sense making and semiology of graphical displays literature to establish a non-ambiguous and comprehensive set of design principles that can be applied to the design of a vital sign chart to improve how the data is presented.

The principle DSR output of this research is the reconciliation of the Design Science Research Methodology (DSRM) process model (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2008) with aspects of the Process Model for Procedurally Transparent (PMPT) DSR (Gleasure, Feller, & Flaherty, 2012). The DSRM approach was identified as a suitable process model for this research as it provided a common language with which to structure the research design and it allowed for research entry points for situated artefacts, however, concerns were raised in chapter 3 regarding ambiguity of the design process. The PMPT process model was designed as a start to finish DSR approach for the design, build and evaluation of an artefact

and presents design phases that encourage formalising design knowledge prior to instantiating the artefact. In order to improve the transparency and perceived rigor of the DSRM approach, elements of the PMPT approach were introduced to the DSRM. This process is discussed in more detail in section 3.3.3.1. The updated DSRM process model is a useful contribution to DSR as it can act as a template for future researchers/designers who need to iterate on situated artefacts but who have concerns over the ambiguity of aspects of the DSRM process model.

Finally, this thesis also builds on the work of Baker et al. (2009), who put forward a research agenda which posited that using visual representations of data can facilitate sense making in data exploration tasks. This thesis identifies important commonalities between the process of data exploration using graphical displays and the phase of information processing performed during clinical reasoning. Furthermore, the data collected from the evaluation of the NEWS, eNEWS and eNEWS V2.0 charts begins to demonstrate the impact of particular aspects of visual representation on the tasks of sense making during data exploration/information processing during clinical reasoning.

1.4. Contributions to the Academic Community

An important component of a scientific research project is to contribute to the relevant academic community and to adequately communicate the important contributions of this research. Table 1.6 presents a list of the current contributions borne from this research.

Publication	Contribution to Thesis
Creedon, F., O'Donoghue, J., O'Kane, T., Adam, F., *An Approach for Reflectively Discovering and Synthesizing Design Knowledge for Situated Artefacts: The Case of the Early Warning Score Chart*, European Design Science Symposium 2013	The approach employed to discover embedded design knowledge in chapter 3 if formalised.
Creedon, F., O'Donoghue, J., O'Kane, T., Adam, F., Woodworth, S., O'Connor, S., *Evaluating the Utility of the Irish HSE's Paper Based Early Warning Score Chart: A Reflective Data Gathering Phase for the Design of the REVIEWS Framework*, DSS 2.0-Supporting Decision Making With New Technologies 261 (2014): 165.	The paper presented the design knowledge embedded in the NEWS chart and presented the methodology for comparatively evaluating the utility of the NEWS chart compared to legacy charts. Analysis of the data collected demonstrated the usefulness of the NEWS chart and helped to identify previously unidentified design principles.

Table 1.6. Pertinent publications to this thesis

Chapter 2 : An Exploration and Critique of Early Warning Systems and Observation Chart Design Literature

2.1. Introduction

The purpose of this chapter will be to first establish an understanding of the principles by which a system can facilitate information processing and then to present a critical analysis of the existing AWTTS chart design literature. In chapter 1 an overview of the research project was presented, as well as a definition of the objective of the research. The objective of this research is concerned with investigating and producing a set of design principles which, when instantiated in an early warning system designed to detect patient deterioration, will have a positive impact on nurses ability to process information presented on electronic vital sign charts. An electronic Aggregate Weighted Track and Trigger System (AWTTS) chart (*i.e. the eNEWS chart,* see Appendix 1 for Early Warning Score instructions) has been identified as a suitable artefact on which the design principles can be instantiated and can then be used to evaluate the usefulness of the design principles. Prior to formulating these design principles, there is first a necessity to establish an understanding of how systems facilitate processing of information and then to critically assess existing vital sign chart design literature.

2.2. An Exploration of Early Warning System Design

While this chapter does not present an in-depth understanding of what design is (this is presented in chapter 3), in order to proceed with this section there is a need to present a high-level understanding of design. Ralph and Wand, (2009) define design as:

> *(noun) a **specification** of an **object**, manifested by some **agent**, intended to accomplish **goals**, in a particular **environment**, using a set of **primitive components**, satisfying a set of **requirements**, subject to some **constraints**.*

(verb, transitive) to create a design, in an environment (where the designer operates)

Considering the two definitions of design as presented above it is logical to state that design can be manifested as an action or a process. A simplified interpretation of the above definition implies that design is a process where an agent (an individual or a group) identifies a desired state (goals) and specifies changes to the object (subject to the constraints of the nature of the environment and the object) that when implemented affect the required changes to the environment (i.e. satisfy the requirements). Inherent to this description of design is having an understanding of both the nature of the problem environment and how the environment can be manipulated through the instantiation of design principles. In the context of this research, prior to exploring design principles for the design of an electronic AWTTS chart, there is first a necessity to formalise an understanding of how AWTTS charts work at a high level. For that reason, this section will present an understanding of how AWTTS charts work at a high level and will present an exploration of systems that perform similar functions. Formalising this knowledge will provide the required background necessary to understand the problem system.

The title of this section refers to an exploration of *Early Warning Systems* (EWS), a term that has not yet been used in this thesis. As such, it may seem out of place, however, at its core an AWTTS chart is a fundamental component of a medical EWS for identifying patients at risk of deterioration. As established in chapter 1, a vital sign chart serves two primary functions: the first is to act as a record of vital signs observed for a patient with the second being to communicate the information in a meaningful way to the carer. It has been established that the act of *considering vital signs presented for a patient* is an important step in the process of identifying patients at risk of deterioration (Silverston, 2013). Medical EWS are designed based on the theory that specific vital sign observations have a correlation with patient outcomes, as such, much of the research associated with AWTTS has been focused on defining the relationships between specific vital sign observations and likely patient outcomes (G. B. Smith, 2013). This research has manifested itself as *Early Warning System Scores*, medical EWS associate specific scores with vital sign observations recorded for pre-defined vital signs ranges. The aggregate of the vital

sign scores (the Early Warning System Score) recorded then dictates a minimum care plan for the patient. The concept is that; by establishing an objective means of identifying patients at risk of deterioration and establishing suitable escalation protocols and care plans for these patients, cases of avoidable sudden deterioration will be mitigated.

However, while initial research into the usefulness of early warning system scores has been positive, there is still an understanding that an early warning system score is still only one element to consider when assessing a patient's health. When assessing a patient, the health professional must take all contextual information into account (i.e. *seeing the whole picture* (Chaboyer & Creamer, 1999)). This notion of *seeing the whole* picture implies that the design of an EWS extends beyond the use of discrete objective values to make predictions. While early warning scores in a clinical context is a relatively new area of academic research, EWS research in general has long been an area of academic interest. As such, knowledge developed for the design of EWS may provide useful insights into the design of medical EWS. Considering this, the following section will present an overview of EWS design literature and will establish the common design elements that contribute to the design of good EWS.

2.2.1. Identifying the Elements of a Successful Early Warning System

From the perspective of using a system to mitigate disaster or loss of human life, EWS applications have an obvious use. Investigating the use of early warning systems from a military perspective is useful as the military has long been noted as an important source of innovation (Thal & Shahady, 2010). It is difficult to ascertain the date of the first use of early warning systems in military, however, an example of early warning systems has been noted in operation during the 30 years' war in the 16th century, where communities developed along the lines of projected army movement in order to warn nearby villages to prepare (Parker, 1996). The type of information provided by these form of EWS was Boolean, i.e. an army was either approaching or not. However, modern EWS must deal with a larger amount of more granular information in order to identify potential risk (Sarkar & Sriram, 2001). In an attempt to improve the design of early warning systems a number of prescriptive

design frameworks have been put forward that describe design tenants that an EWS should subscribe to. Walker, (1989) posits that there are 4 key components to constructing an effective early warning system:

1. *Detection, evaluation and prediction of hazard.*
2. *Constructing a forecast or warning message.*
3. *Spreading the warning message.*
4. *Preparing effective preparedness and mitigation response.*

These 4 components are similarly represented in a report prepared as part of the International Strategy for Disaster Reduction in 2006, who state that:

> *To be effective, early warning systems need to actively involve the communities at risk, facilitate public education and awareness of risk, effectively disseminate messages and warnings and ensure there is a constant state of preparedness.*("Developing Early Warning Systems : A Checklist, by the International Strategy for Disaster Reduction," 2006, pg. 1)

Based on this message, a four element, people-centred early warning system was developed.

Element	Purpose	Checklist of Questions to Ask
1. Risk Knowledge	Systematically collect data and undertake risk assessments.	• Are the hazards and the vulnerabilities well known? • What are the patterns and trends in these factors? • Are risk maps and data widely available?
2. Monitoring & Warning Service	Develop hazard monitoring and early warning services.	• Are the right parameters being monitored? • Is there a sound scientific basis for making forecasts? • Can accurate and timely warnings be generated?

Element	Purpose	Checklist of Questions to Ask
3. Dissemination & Communication	Communicate risk information and early warnings.	• Do warnings reach all of those at risk? • Are the risks and warnings understood? • Is the warning information clear and useable?
4. Response Capability	Build national and community response capabilities.	• Are response plans up to date and tested? • Are local capabilities and knowledge made use of? • Are people prepared and ready to react to warnings?

Table 2.1. Four Elements of People-centred Early Warning Systems Source ("Developing Early Warning Systems : A Checklist, by the International Strategy for Disaster Reduction," 2006)

While some of the terminology presented for Walker's approach and the *four elements* approach are different, the spirit of each phase seems to be the same:

- *Detection, evaluation and prediction* is analogous to *risk knowledge,*
- *Constructing a forecast or warning message* is analogous to *Monitoring & warning service,*
- *Spreading the warning message*, is analogous to *dissemination & communication and*
- *Preparing effective preparedness and mitigation response* is analogous to *response capability.*

While there appears to be no references that tie the development of the four elements approach to Walker's components for a successful EWS, these two approaches fundamentally employ the same underlying principles. They represent a holistic perspective of EWS design, where the questions asked include everything from the systematic collection of data, to the scientific analysis of data, to how the data is then communicated in order to allow individuals to carry out actions that mitigate risk. Considering the consistency in the literature regarding the elements or components that are required to develop a good EWS, it is reasonable to assume that the

questions asked in the four elements approach can provide a useful way for decomposing the design of a EWS. The following section will employ the Irish HSE's paper-based NEWS chart as a specific example on which to decompose the elements of a medical EWS. This will serve two purposes:

- First, will be to present an understanding of how an AWTTS chart is designed from a holistic perspective and
- Second, it will provide an opportunity to identify potential weaknesses in the design of an AWTTS system.

2.2.2. Decomposing the Four Elements of an AWTTS

As established in section 2.2.1, the four elements of people-centred early warning systems and in particular the checklist of questions that are asked can provide a basis for decomposing the design of an early warning system. This section will present an analysis of the Irish HSE's NEWS system from this perspective. This will provide an opportunity to identify the individual components of the system, but can also present an opportunity to:

- Further understand the nature of the NEWS system,
- Identify the problems with the design of the existing system and
- Formalise potential approaches for improving the design of the system.

The NEWS system and associated COMPASS training program was introduced by the Irish HSE in 2012. The Irish HSE employs the following definition of the NEWS System:

> *Early Warning Scores facilitate early detection of deterioration by categorising a patient's severity of illness and prompting nursing staff to request a medical review at specific trigger points utilising a structured communication tool while following a definitive escalation plan. Adopting a National Early Warning Score (NEWS) is beneficial for standardising the assessment of acute illness severity, enabling a more timely response using a common language across acute hospitals nationally* (National Clinical Effectiveness Committee, 2013, pg. 4).

By identifying patients at risk of deterioration and pre-emptively adjusting their care plan it is expected to mitigate against avoidable patient deterioration (Avard et al., 2011). The NEWS system is a form of Aggregate-Weighed Track and Trigger System (AWTTS). The Irish HSE employs the following definition of an AWTTS:

> *An aggregate score is a collection of scores from individual physiological observations that are added together to form a total score. Each of the physiological parameters are weighted e.g. for the most part physiological observations considered normal are allocated a score of 0, those outside this are allocated higher scores, i.e. they are weighted according to the deviation from the norm* (National Clinical Effectiveness Committee, 2013, pg. 22).

> *A 'track and trigger' tool refers to an observation chart that is used to record vital signs or observations graphically so that trends can be 'tracked' visually and which incorporates a threshold (a 'trigger' zone) beyond which a standard set of actions is required by health professionals if a patient's observations breach this threshold* (Clinical Excellence Commission, 2010. pg. 8).

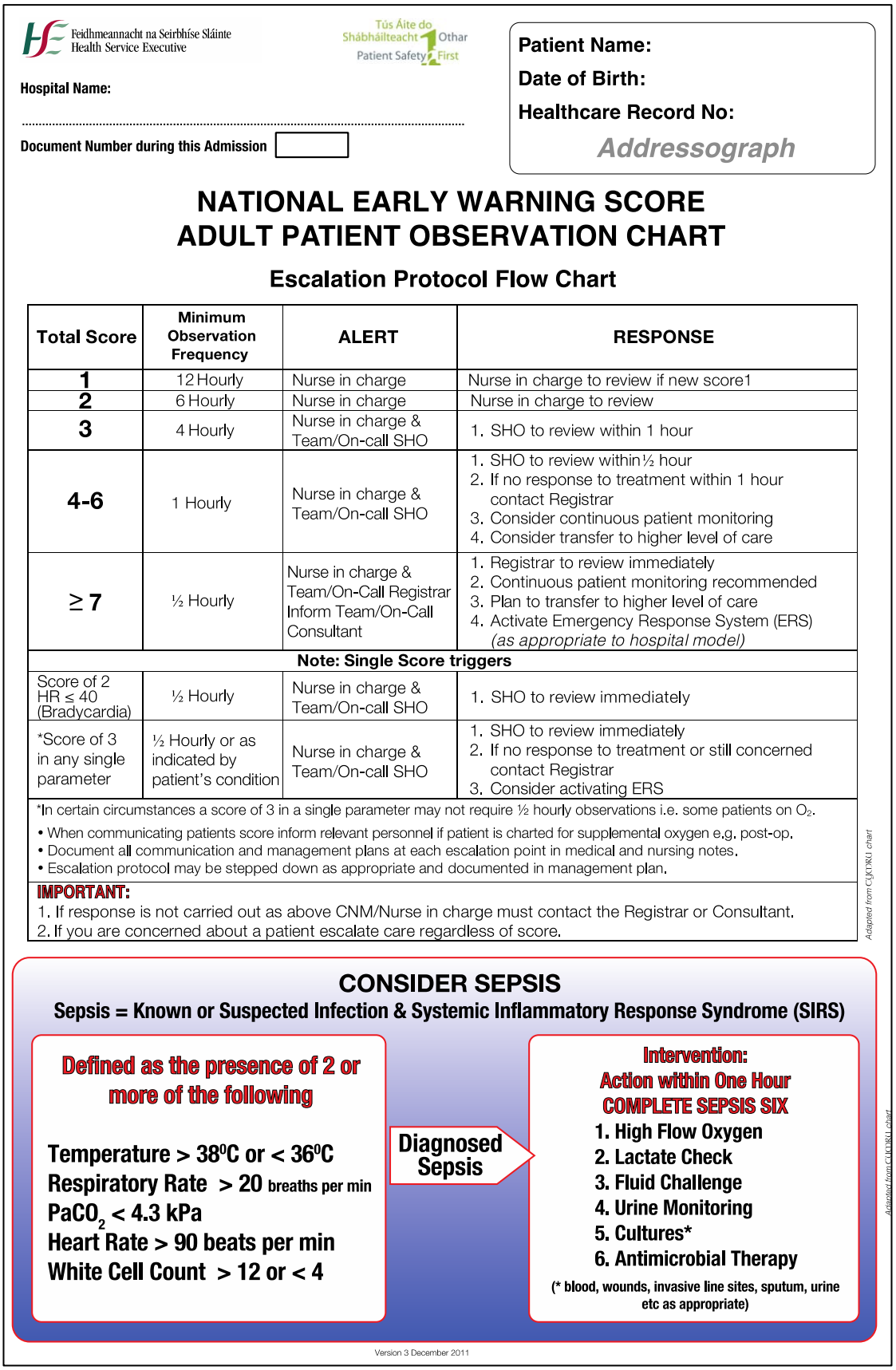
This is consistent with the description of AWTTS as presented by (Ludikhuize, de Jonge, Goossens, & Jonge, 2011; Patel, Jones, Jiggins, & Williams, 2011; Prytherch et al., 2010). The Irish HSE defines the COMPASS Education programme as:

> *An interdisciplinary education programme designed to enhance our health care professionals' understanding of patients who are clinically deteriorating and the significance of altered clinical observations. It also seeks to improve communication between healthcare professionals, while adopting a patient-centred quality driven approach and enhancing the timely management of patients. The programme incorporates education on the use of the National Early Warning Score* ("About the NEWS and COMPASS Education Programme," 2015).

The NEWS chart is a central component of the NEWS system, it acts as a platform for recording vital sign observations and also provides a template for presenting the

care plan policy for patients, as well as presenting the vital sign information in a meaningful way to nurses. This chart also presents further information on care protocols and reference sections for calculating the early warning score. The 3 pages of the NEWS chart are presented in Figure 2.1, Figure 2.2 and Figure 2.3. As the NEWS system is paper based, there is a reliance on the nurses using the chart to accurately interact with the chart and to precisely follow care protocols dictated by the early warning score for the individual patient.

Having presented an overview of the NEWS system and the processes associated with the system, it is now useful to examine the four elements of people-centred early warning systems. This is necessary as the four elements approach was developed to help guide the design of early warning systems to mitigate natural or man-made geographical disaster. As such, there are a few definitions that need to be explored so the approach can be suitably applied to the design of an AWTTS for caring for individual patients at risk of deterioration. Sections 2.2.2.1 to 2.2.2.4 present an understanding of each of the four elements of the design for good early warning systems and the questions associated with each element. In order to present an understanding of each element practical examples relating to natural disaster are presented along with analogous medical examples then given that relate to the use of an AWTTS.



Feidhmeannacht na Seirbhíse Sláinte
Health Service Executive

Tús Áite do Shábháilteacht Othar
Patient Safety First

Hospital Name:

.....

Document Number during this Admission

Patient Name:
Date of Birth:
Healthcare Record No:
Addressograph

NATIONAL EARLY WARNING SCORE
ADULT PATIENT OBSERVATION CHART

Escalation Protocol Flow Chart

Total Score	Minimum Observation Frequency	ALERT	RESPONSE
1	12 Hourly	Nurse in charge	Nurse in charge to review if new score1
2	6 Hourly	Nurse in charge	Nurse in charge to review
3	4 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within 1 hour
4-6	1 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within½ hour 2. If no response to treatment within 1 hour contact Registrar 3. Consider continuous patient monitoring 4. Consider transfer to higher level of care
≥ 7	½ Hourly	Nurse in charge & Team/On-Call Registrar Inform Team/On-Call Consultant	1. Registrar to review immediately 2. Continuous patient monitoring recommended 3. Plan to transfer to higher level of care 4. Activate Emergency Response System (ERS) *(as appropriate to hospital model)*
Note: Single Score triggers			
Score of 2 HR ≤ 40 (Bradycardia)	½ Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review immediately
*Score of 3 in any single parameter	½ Hourly or as indicated by patient's condition	Nurse in charge & Team/On-call SHO	1. SHO to review immediately 2. If no response to treatment or still concerned contact Registrar 3. Consider activating ERS

*In certain circumstances a score of 3 in a single parameter may not require ½ hourly observations i.e. some patients on O_2.

- When communicating patients score inform relevant personnel if patient is charted for supplemental oxygen e.g. post-op.
- Document all communication and management plans at each escalation point in medical and nursing notes.
- Escalation protocol may be stepped down as appropriate and documented in management plan.

IMPORTANT:
1. If response is not carried out as above CNM/Nurse in charge must contact the Registrar or Consultant.
2. If you are concerned about a patient escalate care regardless of score.

Adapted from CJUOHU chart

CONSIDER SEPSIS

Sepsis = Known or Suspected Infection & Systemic Inflammatory Response Syndrome (SIRS)

Defined as the presence of 2 or more of the following

Temperature > 38°C or < 36°C
Respiratory Rate > 20 breaths per min
$PaCO_2$ < 4.3 kPa
Heart Rate > 90 beats per min
White Cell Count > 12 or < 4

Diagnosed Sepsis

Intervention:
Action within One Hour
COMPLETE SEPSIS SIX
1. High Flow Oxygen
2. Lactate Check
3. Fluid Challenge
4. Urine Monitoring
5. Cultures*
6. Antimicrobial Therapy

(* blood, wounds, invasive line sites, sputum, urine etc as appropriate)

Adapted from CJUOHU chart

Version 3 December 2011

Figure 2.1. NEWS chart page 1: Escalation protocol. Source HSE.ie

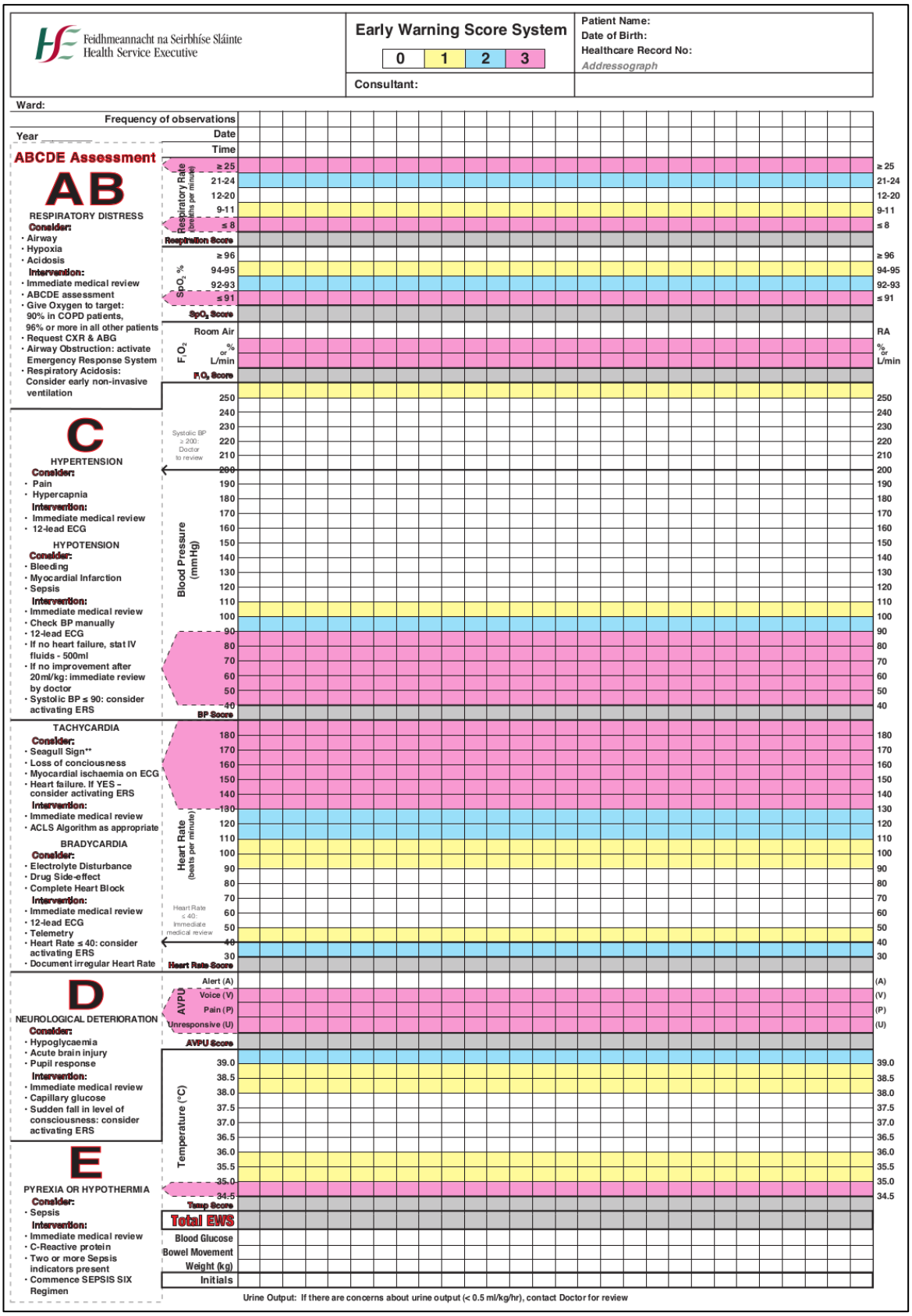
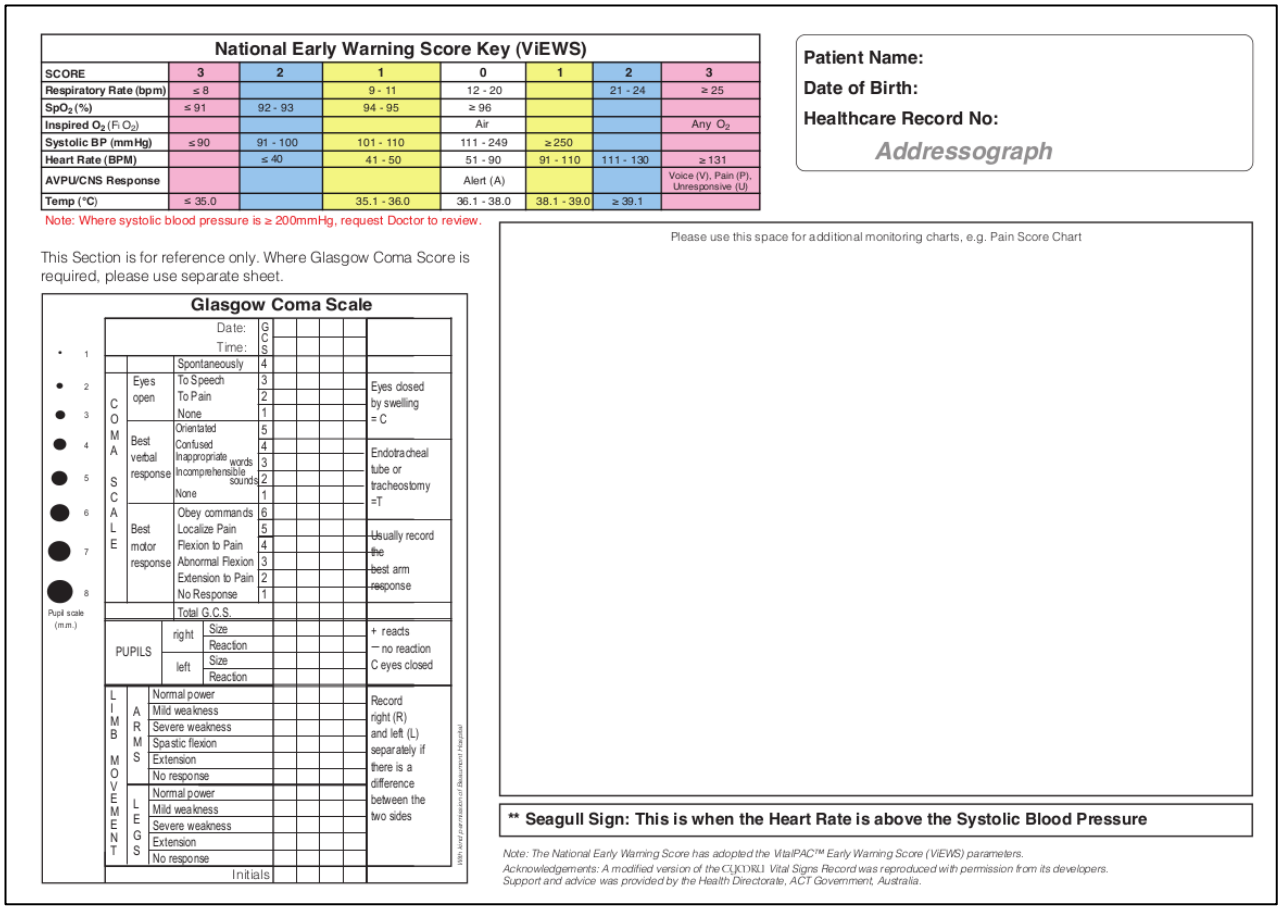


Figure 2.2. NEWS chart page 2: Vital sign chart. Source HSE.ie



National Early Warning Score Key (ViEWS)

SCORE	3	2	1	0	1	2	3
Respiratory Rate (bpm)	≤ 8		9 - 11	12 - 20		21 - 24	≥ 25
SpO_2 (%)	≤ 91	92 - 93	94 - 95	≥ 96			
Inspired O_2 ($Fi O_2$)				Air			Any O_2
Systolic BP (mmHg)	≤ 90	91 - 100	101 - 110	111 - 249	≥ 250		
Heart Rate (BPM)		≤ 40	41 - 50	51 - 90	91 - 110	111 - 130	≥ 131
AVPU/CNS Response				Alert (A)			Voice (V), Pain (P), Unresponsive (U)
Temp (°C)	≤ 35.0		35.1 - 36.0	36.1 - 38.0	38.1 - 39.0	≥ 39.1	

Note: Where systolic blood pressure is ≥ 200mmHg, request Doctor to review.

Patient Name:

Date of Birth:

Healthcare Record No:

Addressograph

This Section is for reference only. Where Glasgow Coma Score is required, please use separate sheet.

Glasgow Coma Scale

				GCS
Date:				
Time:				
COMA SCALE	Eyes open	Spontaneously	4	Eyes closed by swelling = C
		To Speech	3	
		To Pain	2	
		None	1	
	Best verbal response	Orientated	5	Endotracheal tube or tracheostomy =T
		Confused	4	
		Inappropriate words	3	
		Incomprehensible sounds	2	
		None	1	
	Best motor response	Obey commands	6	Usually record the best arm response
		Localize Pain	5	
		Flexion to Pain	4	
		Abnormal Flexion	3	
		Extension to Pain	2	
		No Response	1	
Total G.C.S.				
PUPILS	right	Size		+ reacts — no reaction C eyes closed
		Reaction		
	left	Size		
		Reaction		
LIMB MOVEMENT ARMS		Normal power		Record right (R) and left (L) separately if there is a difference between the two sides
		Mild weakness		
		Severe weakness		
		Spastic flexion		
		Extension		
		No response		
LEGS		Normal power		
		Mild weakness		
		Severe weakness		
		Extension		
		No response		
Initials				

Pupil scale (m.m.): 1 2 3 4 5 6 7 8

With kind permission of Beaumont Hospital

Please use this space for additional monitoring charts, e.g. Pain Score Chart

**** Seagull Sign: This is when the Heart Rate is above the Systolic Blood Pressure**

Note: The National Early Warning Score has adopted the VitalPAC™ Early Warning Score (ViEWS) parameters.

Acknowledgements: A modified version of the CUCOR1 Vital Signs Record was reproduced with permission from its developers. Support and advice was provided by the Health Directorate, ACT Government, Australia.

Figure 2.3. NEWS chart page 3: Reference section. Source HSE.ie

2.2.2.1. Risk Knowledge

The purpose of the risk knowledge element is to *'Systematically collect data and undertake risk assessments',* with the element asking the following questions:

- Are the hazards and the vulnerabilities well known?
- What are the patterns and trends in these factors?
- Are risk maps and data widely available?

From these three questions some key words can be extracted. *Hazards* and *vulnerabilities*, from a geographical perspective, for instance refer to events such as earthquakes, tornadoes or tsunamis, that is to say events that constitute some kind of risk or disaster.

In the case of the NEWS system the nurses who are the primary user of the system will have been trained to observe risks such as respiratory distress, tachycardia or neurological deterioration. The NEWS chart also presents potential hazards in the form of the *ABCDE assessment tool* (see Figure 2.2) and the *consider sepsis* section (see Figure 2.3).

Patterns and trends refer to historical data about vulnerabilities for a particular natural disaster. For example, in the case of earthquakes it has been observed that non-damaging primary waves (P-wave) arrive at a location prior to the damaging secondary wave (S-wave). By analysing data about the P-wave, the magnitude of the S-wave can be estimated (Allen & Kanamori, 2003), (i.e. P-wave data can be analysed for patterns and trends to predict the severity of S-waves).

From the perspective of using the NEWS system, patterns and trends about a particular patient can be observed through reviewing the patient's vital sign data that has been recorded over time in the NEWS chart (see Figure 2.2). Observing these patterns and trends is reliant on the quality of how the data is presented and the nurse's cognitive capacity in terms of searching for information presented on the observation chart.

Risk maps, refers to having geographical maps that demonstrate areas of risk. A risk map is essentially a means of presenting data about geographical risk in a meaningful way.

In a medical context the NEWS chart performs this function for individual patients. Presenting vital sign information on a graph over time can demonstrate areas of concern for a patient, for example: if a patient has increased blood pressure over a period of time this can be quickly detected by reviewing the NEWS chart.

2.2.2.2. Monitoring & Warning Service

The purpose of the monitoring and warning service element is to *'develop hazard monitoring and early warning services'* and must answer the following questions:

- Are the right parameters being monitored?
- Is there a sound scientific basis for making forecasts?
- Can accurate and timely warnings be generated?

The initial two questions of this element *are the right parameters being monitored* and *is there a sound scientific basis for making forecasts* are interrelated. The former questions relates to whether the correct parameters that can help to predict disaster are being collected and analysed. The latter question asks whether there is a sound scientific basis for making predictions based on the parameters being monitored. These questions are interrelated, as a sound scientific method will help to ensure that the right parameters are being monitored.

From the perspective of a medical EWS, *early warning score* research continues to analyse vital sign data preceding patient deterioration in order to identify correlations. At the time of designing the NEWS system the Irish HSE based the vital signs being recorded on the research conducted by Prytherch et al., (2010). The use of the early warning score system developed by Prytherch et al. was observed as having a significant positive impact on nurse's ability to identify patients at risk of deterioration. While early warning score research continues to refine algorithms for predicting patient deterioration, it can be observed that the NEWS system is monioring appropriate parameters that have been developed using a sound scientific basis.

The third question is regarding the accuracy and timeliness of warning messages. Accuracy and timeliness are an important component of any system that is designed to help avoid disaster as miscommunication of the message can lead to hazardous

results. In the case of the NEWS system, it is reliant on the nurse who records the vital signs, calculates the early warning score and makes the necessary communication. Chapter 1 describes the COMPASS training program associated with the NEWS system that the Irish HSE developed for ensuring that nurses are able to use the system in a timely and accurate way. While this aspect of the NEWS system is dependent on human competency, this training system should generally improve the accuracy and timeliness of the warning generated from the use of the NEWS system.

2.2.2.3. Dissemination & Communication

The purpose of the dissemination and communication element is to *'communicate risk information and early warning'*, with the questions being asked of the element being:

- Do warnings reach all of those at risk?
- Are the risks and warnings understood?
- Is the warning information clear and useable?

In the case of a geographical EWS, communicating to those at risk is a necessity, as it is likely that those at risk are the individuals likely to be adversely impacted by the impending disaster and there is a necessity for these individuals to create an intervention to avoid personal loss.

In the case of the NEWS system, the individual at risk does not necessarily have the expertise to create an intervention that can mitigate risk. For example, a patient in the case of a hospital can-not dictate their own care plan. In this case it is more important that the warning is communicated to the nurse caring for the patient. Furthermore, in cases where escalated care is required for the patient there may be a necessity for the warning message to be communicated to doctors. As such, NEWS needs to first warn the individual nurse who is caring for the patient. As part of the COMPASS training program, nurses are trained to understand the meaning of the early warning scores and there is a requirement for them to recognise elevated scores. Furthermore experiential learning allows nurses to recognise other signs of deterioration including objective information such as trends presented on the vital sign chart and subjective

information such as patient pallor (Jane Cioffi et al., 2010). Having established whether a patient is at risk of deterioration, there is then a necessity for the individual nurse to communicate with other stakeholder such as the patient themselves or doctors or family members.

Risks and warnings being understood is achieved through both the nurse's experiential knowledge and the COMPASS education program which trains nurses regarding all aspects of use of the NEWS system (Kuiper & Pesut, 2004; Radwin, 1998). How clear and useable the warning message is, is dependent on how well the nurse understands how to use the NEWS system. Familiarising users with the use of a new system is dependent on the quality of training provided (Ludwick & Doucette, 2009), as such this element is dependent on the quality of the education provided by the COMPASS education programme.

2.2.2.4. Response Capability

The purpose of the response capability element is to *'build national and community response capabilities',* with the element asking the following questions:

- Are response plans up to date and tested?
- Are local capabilities and knowledge made use of?
- Are people prepared and ready to react to warnings?

In the case of the NEWS system, the Irish HSE introduced the COMPASS education programme (described in section 2.2.2) in order to enhance nurse's understanding of the nature of the system and best practice surrounding the use of the system. The training program is designed to ensure that nurses using the NEWS system are familiar with response plans. These response plans are designed by the academic community concerned with Early Warning Score research. This research aims to match early warning scores with appropriate response plans, therefore increasing the likelihood that response plans are up to date and tested.

From a geographical disaster perspective, making use of local capabilities and knowledge refers to making use of resources that can be valuable which are physically located near to the disaster area. In a healthcare context this can be interpreted as making use of resources such as medical knowledge or other

healthcare resources in a hospital. In the context of the NEWS system, local capabilities and knowledge being made use of can be observed in the nature of the multi-disciplined teams who engage with the system. NEWS requires nurses to act as the primary user of the system where they record vital sign observations, calculate the early warning score and communicate the patient's condition with others and in cases where elevated care is required they then need to contact either more senior nurses or the doctor on call. Depending on the minimum care-plan identified for the patient, there may then be a necessity for the doctor to visit the individual patient and possibly make a care intervention for the patient.

Finally, the COMPASS education program formalises and educates nurses regarding preparedness and how to react when the NEWS system triggers elevated care plans for an individual patient.

2.2.3. The NEWS Systems Reliance on Human Information Processing Capacity

Sections 2.2.2.1 to 2.2.2.4 have so far presented a decomposition of the NEWS system from the perspective of the four elements of people-centred early warning systems. While this four-element framework was developed initially for natural or military disaster risk mitigation systems, these sections also demonstrated how the framework could be applied to a medical EWS, using the NEWS system as an exemplar. From the perspective of the NEWS, many of the questions have been adequately addressed, however, for a number of the questions there was a dependence on human competence present in the system. For example consider the risk knowledge element. As healthcare is a specialist area and working in a busy hospital can be difficult, mistakes can be made when identifying hazards and observing trends in deterioration (Liu, 2008). Furthermore, there is an acceptance that the NEWS system is not a "silver-bullet" for identifying deteriorating patients (Avard et al., 2011). There is still a requirement for nurses to take the time to adequately perform clinical reasoning for each individual patient. As human error is always a factor when considering a patient (Graber, Gordon, & Franklin, 2002), it is logical to assume that any aspect of an early warning system that depends on human competence is also likely to be subject to human error which may in turn lead to a

weakness in the system. Considering this, it is useful to reflect on section 2.2.2 and identify each question that demonstrates a dependence on human competency.

Element	Questions?	Paper-Based NEWS Chart
Risk Knowledge	• Are the hazards and the vulnerabilities well known? • What are the patterns and trends in these factors? • Are risk maps and data widely available?	• Hazards and vulnerabilities are known through experiential learning. • Nurse can learn patterns and trends of deterioration, observation chart used as source of information for finding these patterns and trends. • Hand drawn vital sign graph can act as a risk map for individual patients.
Monitoring & Warning Service	• Can accurate and timely warnings be generated?	• Warnings are only as accurate and timely as nurse accuracy and cognitive capacity.
Dissemination & Communication	• Do warnings reach all those at risk? • Are the risk and warnings understood? • Is the warning information clear and useable?	• Warnings are only communicated if nurse does so. • The risks and warnings are pre-defined by Irish HSE. • Warning information is only as clear as how well it is manually written.
Response Capability	• Are people prepared and ready to react to warnings?	• Nurses nationally are trained on NEWS response.

Table 2.2. Analysis of human dependency in the NEWS system from the perspective of the four elements of good early warnings system design.

As Table 2.2 demonstrates the NEWS system is reliant on human competence for a number of the questions that are asked for the *four elements framework for people-centred early warning system design*. Consider for example the *risk knowledge* element, where vital sign data is only stored on paper. While paper is an adequate

means for recording and presenting vital sign data, it presents a bottleneck in terms of facilitating easy communication of risk. Furthermore, the *monitoring & warning service* is also limited due to the manual nature of recording vital signs and calculating early warning scores. From a *dissemination & communication perspective,* there is also a possible risk arising from manual processes. Firstly, warning messages can only be adequately communicated if the nurse correctly communicates the message. Secondly, how well the information is communicated is limited by how well the nurse is able to communicate the vital sign information in either verbal or written form. Each of these issues are dependent on the accuracy of either verbal or written communication, as such, these issues are subject to human error and may be limited to the individual's understanding of the warning. Considering the bottlenecks associated with errors in human accuracy and human cognitive capacity, it is useful to present some early warning systems that are designed to negate these bottlenecks.

2.2.4. Can the Human Error Factor be eliminated?

Section 2.2.3 described a medical EWS from the perspective of the four elements of an early warning system and established that there were some potential weaknesses in the system due to its dependency on human competency. In the executive summary of Kohn et al.'s book *To Err is Human* (2000), the cases of studies in three hospitals in Colorado, Utah and New York were presented. In these studies it was established that of the adverse effects that happened during hospitalisation, over 50% of the events were a result of human error. As such, it is logical to assume that if a medical EWS could be designed to eliminate human error then it will likely be more successful. For the sake of discussing such a system, it is useful to present an EWS that is designed to eliminate the bottleneck of human input.

Research in designing motor vehicles (MVs) that eliminate human error has been around in one form or another since the early 1900's, with Anti-lock Braking Systems (ABS) being developed to support the driver in applying the correct braking pressure when slowing down and avoiding accidents. At the time of writing the current goal is to develop self-driving MVs which can completely eliminate human input when driving. The goal of these systems is ultimately to avoid otherwise

avoidable accidents that are the result of human input error or human judgement error. Much of the systems used to avoid human error employ a number of sensors to understand the external environment and avoid accidents. One example of an EWS for MVs is the case of the self-braking car.

While much of the scientific research conducted by private firms for the development of self-braking cars is not shared publically, details of the design of the artefacts are often available in the form of patents. As such, this section will present an analysis of motor vehicle early warning systems based on a patent identified on *scholar.google.com*. While a number of MV EWS exist, such as driver drowsiness detection and lane departure detection, this analysis will concentrate on early warning systems that trigger vehicle breaking (Rahman, 2000). Analysis of this MV EWS is presented in Table 2.3.

Element	Motor Vehicle Early Warning System
Risk Knowledge	• Brake activation signal is transmitted from one vehicle to another via a transmitter at the rear of each vehicle and receiver at the front of each vehicle.
Monitoring & Warning Service	• Receiver is designed to automatically receive input from vehicle in front to communicate braking.
Dissemination & Communication	• Transmitter at the rear of vehicle sends breaking information. • Control unit in vehicle manipulates information received to be useful.
Response Capability	• Control unit can trigger automatic braking if necessary.

Table 2.3. Motor-vehicle early warning system. Source (Rahman, 2000)

While the example of the MV EWS presented in Table 2.3 may not be a perfect example of a EWS that can completely avoid accidents and the analysis of the system is parsimonious, it presents an interesting solution in that it bypasses an important factor in MV accidents, i.e. human error. Human error has been estimated to be a factor in over 90% of MV crashes (B. W. Smith, 2013) and much research in the development of motor vehicles has been centred on eliminating the human error

factor. The EWS presented in Table 2.3 represents an EWS that aims to eliminate human error through automated systems. While this may be an appropriate solution for MVs, the question that arises is whether this is an appropriate solution for early detection of deterioration of the health of patients in hospital. In the case presented in Table 2.3, the scenario is quite simple, if the fore-running vehicle applies braking pressure, then the vehicle behind the car will also apply automatic braking making sure that the following vehicle does not come to close to the fore-running vehicle. This invention assumes that the only contributing factors necessary to avoid rear-end collisions is knowing the distance between vehicles and knowing the braking pressure applied in each vehicle. While this may be a complicated system, it is not considered to be complex as the variables are known and the appropriate response is also known. This however, is not typically the case when making care decisions for patients at risk of deterioration (J Cioffi & May, 1998).

In the case of caring for a patient in a complex environment such as a hospital, it becomes much more difficult to make care decisions for the patient. While the NEWS system employs a limited number of discrete vital sign observations to create an early warning score, there is an acceptance that this approach should not replace clinical judgement and should instead act as an aid for highlighting patients who are potentially deteriorating. Clinical reasoning relies not only on making decisions based on discrete values (i.e. vital signs), but clinical reasoning also requires the individual nurse to employ critical thinking and is also influenced by individual bias and socially created philosophical perspectives (Forsberg, Ziegert, Hult, & Fors, 2013). Furthermore, the training literature for the NEWS system also emphasises that nurses use their clinical reasoning skills when interacting with the NEWS system (Avard et al., 2011). Considering this emphasis placed on individual clinical reasoning and clinical judgement and the complexity of making care decisions for patients, it can be stated that; any approach for improving the design of a medical EWS should focus on supporting the individual decision maker as opposed to eliminating their input from the process.

2.2.5. Can Human Judgement be Facilitated?

Having established in the previous section that it is not feasible to bypass human judgement from making care decisions when using a medical EWS, it is now necessary to present an understanding of how an information system such as NEWS can be designed to facilitate human judgement. Systems that facilitate human judgement typically take the form of a Decision Support System (DSS). DSS are designed based on the idea that electronic systems (as an information system) can focus on the of content and presentation of data in order to support decision making process (McCosh & Morton, 1978; Newell & Simon, 1972). Hasan & Gould (2001), observe that the nature of decision making in complex situations is "messy" and that decisions are made by individuals based on their experiential knowledge, cognitive capacity, personality and cultural bias. Hasan & Gould, observe that when making decisions in this kind of environment it is rarely a case of simply applying knowledge to a problem and is instead a sense-making activity where individuals perform information processing to structure complex problems.

This view of decision making is divergent to that of the concept of the human as a rational decision maker as posited by Simon, (1955) who suggests that if all the given parameters that affect a decision are known then an individual can make a rational choice. Instead, this view of supporting sense-making has more in common with Naturalistic Decision Making (NDM). Lipshitz, et al., (2001, pg. 2) describe NDM as *an attempt to understand how people make decisions in real-world contexts that are meaningful and familiar to them,* with Lipshitz, (1995) observing that there are five converging themes in the study of NDM. These are:

1. Diversity in form *(Decisions are made in a variety of ways)*
2. Blend of intuition and analysis
    a. *Situation Assessment (Problem is identified by the decision maker)*
    b. *Use of mental imagery*
3. Context Dependant
4. Dynamic Processes (*Decision makers switch between intuitive and analytic decision making as a function of changing task requirements*)

5. Description-based prescriptions *(Study experts and then develop methods for improving decision quality, either by emulating these experts or by designing decision support systems, which are compatible with human information processing and knowledge-representation methods)*

Considering themes 2 to 4, the following observation about how nurses make care decisions in pre-cardiac arrest situations is relevant:

> *The cue that nurses most often described was acute change in conscious state. This change was an important cue; however, changes were often subtle and based on knowledge of the patient's baseline mental status. In addition to evaluating physiologic variables, the nurses evaluated a patient's potential instability within the context of the situation and considered factors such as the patient's history and severity of illness, information from shift reports and the patient's baseline. When any of these sources of information were ambiguous, nurses increased surveillance to find confirmatory data for use in their decision making* (Gazarian, Henneman, & Chandler, 2010, pg. 31).

What can be observed in this quote is that, the decisions made by nurses in this situation require a *blend of intuition and analysis*, nurses need to consider both physiological variables (analytic subjective information) and the patient's baseline mental status (intuitive knowledge about the patient). Decisions are context dependent (i.e. What is the context of the patient? What is the patient's history?). Furthermore, G. A. Klein, (1993) recognises that nurses making decisions in critical care situations employ dynamic decision making processes. Additionally, the means of developing systems that are designed based on *description-based prescriptions* is also compatible with the nature of decision making by nurses, where it has been observed that:

> *Unfortunately, Western culture in general has proposed replacing intuitive judgements with rational calculations. Rational calculation, apparently, is being confused with human reasoning and is being*

> *mistakenly proffered as the epitome of knowledge. One consequence of this mistake is a false dualism: analytic reasoning versus mysticism. But intuitive knowledge and analytic reasoning are not in an either/or opposition; they can-and often do-work together* (Benner & Tanner, 1987, pg. 31).

Considering the importance of not simply replacing human judgement and reasoning with rational systems, there is a necessity to formalise an understanding of the processes that nurses employ in order to make care decisions for patients at risk of deterioration.

This chapter has thus far observed that a medical EWS can support nurses in the detection of patients at risk of deterioration. The chapter has also concluded that human error can potentially be an area of weakness in the system. While avoiding any areas in which human error can happen is important, there is also a necessity to design a medical EWS in a way that can support the information processing tasks performed by nurses when making sense of a situation. Prior to presenting the design of said interface, there is first a necessity formulate an understanding of how existing medical EWS have been designed and then to assess the usefulness of existing medical EWS. In order to achieve this, the remainder of this chapter will present a critical analysis of literature pertaining to the current state of the art of AWTTS observation chart design, with chapter 4 presenting an evaluation of the usefulness of two situated AWTTS observation charts.

2.3. A Critical Analysis of AWTTS Chart Design Literature

Section 2.2 presented the elements of a successful EWS and presented an analysis of the Irish HSE's NEWS medical EWS from the perspective of these four elements. It was established that the system adequately addresses most of the questions asked of these elements; however, it was also observed that human error could be a contributing factor to inefficiencies in the system. It was observed that the accuracy and completeness by which an early warning score is calculated is dependent on human accuracy and that making sense of information presented on the chart can be limited by the individual decision maker's cognitive capacity. Section 2.2 also

observed that processes associated with medical EWS could be improved through automating processes; however, there is still a necessity for the individual decision maker to use their own judgement and clinical reasoning skills to make care decisions for the patient. The objective of this research is concerned with the latter and it is from this perspective that a critical analysis of Medical EWS interface design literature will be performed. This research is focused specifically on Aggregate Weighted Track and Trigger (AWTTS) observation chart design and as such, this section will focus on pre-existing AWTTS observation chart design literature.

In order to establish a coherent and adequately comprehensive review of the AWTTS chart design literature, this research employed a literature review to identify literature pertaining to AWTTS chart design. A review of three leading scientific research databases was performed (JSTOR, EBSCO and ScienceDirect) using the terms “AWTTS Chart Design”, “Aggregate Weighted Track and Trigger Chart Design”, “EWS Chart Design” and “Early Warning Score Chart Design” and 17 papers were identified which could be relevant to AWTTS Chart Design. Of these 17 papers, 2 papers were directly related to AWTTS Chart Design, with three papers noting the importance of AWTTS Chart design in regard to supporting nurses in identifying patients at risk of deterioration. A review of the references in the 2 papers directly concerned with AWTTS chart design helped to identify a further body of literature regarding the design of AWTTS charts. This body of literature was primarily created by a group of researchers associated with a program for developing standardised AWTTS charts in Australia and New Zealand. This literature includes government reports, conference papers and journal articles and produced a further 17 papers that were directly related to the design of AWTTS charts. The relatively small number of results regarding AWTTS chart design reflects that the use of AWTTS charts is still a relatively new development and furthermore it is a reflection of the nature of design problems. That is to say, design problems often present unstable requirements and constraints based upon ill-defined environmental contexts, complex interactions among subcomponents of the problem and the solution, i.e. they represent “Wicked Problems” (Hevner, March, Park, & Ram, 2004). Considering this, it is logical that a small literature pool will exist. From a review of

the literature regarding the design of the AWTTS charts by this group, it became clear that a human factors design approach was employed. Prior to presenting a critique of the AWTTS chart design literature it is first necessary to present an understanding of what is meant by human factors design.

2.3.1. Human Factors Design

Human Factors (HF) research is a well-established research discipline and has been employed successfully in the design of health artefacts such as: checklists, assessments and decision making protocol (Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004). While there is enough evidence of human factors research that demonstrates the utility of the discipline, in order to evaluate the application of human factors design principles to AWTTS charts, there is a necessity to formalise an understanding of the characteristics of the human factors research discipline. This section will therefore present an overview of what is understood by human factors design. Inherent to the notion of HF design, is that of design itself, section 2.2 presented an overview of this research's perspective of design:

> *Design is a process where an agent (an individual or a group), identify required changes (goals) and specify changes to the object (that are subject to the constraints of the nature of the environment and the object) that when implemented affect the required changes to the environment (i.e. satisfy the requirements). Inherent to this description of design is having an understanding of both the nature of the problem environment and how the environment can be manipulated through the instantiation of design principles.*

This definition of design implies that the result of design (i.e. the artefact) should be designed to affect a required change on a problem system; furthermore this definition implies that knowledge of the problem system is necessary to design the artefact. Having presented this overview of design, it is now useful to present some definitions that help to illustrate the practice of HF design research.

> *Human factors research has been described as the scientific study of the relationship between man and his working environment. In this sense, the term environment is taken to cover not only the ambient environment in which he may work but also his tools and materials, his methods of work and the organization of the work, either as an individual or within a working group. All these are related to the nature of man himself, to his abilities, capacities and limitations* (Murrell, 1965).

> *Human Factors research involves designing artefacts to be usable and useful for the people who are intended to benefit from them* (Tory & Möller, 2004).

These definitions are similar to the definition of design presented above in that the design is concerned with affecting a required change on a problem system. However, what becomes clear from these definitions of HF design is that it is directly concerned with designing artefacts based on an understanding of humans and their interaction with the problem system. While the literature pertaining to AWTTS chart design refers to this kind of design for humans as Human Factors design, this kind of research is more typically referred to as Human Computer Interaction (HCI) research within the IS community (Zhang et al., 2002), with Beard & Peterson, (1988) describing HF research in IS as:

> *The scientific study of the interaction between people, computers and the work environment. The knowledge gained from this study is used to create information systems and work environments which help to make people more productive and more satisfied with their work life.*

Hewett et al., (1992) described HCI as:

> *A discipline concerned with the design, evaluation and implementation of interactive computing systems for human use with the study of major phenomena surrounding them.*

From these definitions a few characteristics of HF research can be extracted. Ontologically (i.e. *what's out there to know*), it can be observed that human factors research asks questions about the individual, their work environment and the artefacts that the individual uses in their work environment. Furthermore, from an epistemological perspective (i.e. *what and how can we know about it*), it can be observed that the questions that are asked about the interaction between man, the work environment and the artefact are design questions. While design can be viewed from multiple perspectives, a perspective that employs design principles implies that detailed specifications for the design of the artefact must be established prior to creating the artefact (R. R. Hoffman, Roesler, & Moon, 2004). This implies that theoretical knowledge of the individual, their work environment and knowledge about the artefact itself must be established prior to creating the artefact. In the case of the literature pertaining to the design of AWTTS charts, a heuristic analysis approach was employed to discover and formalise knowledge about situated observation chart designs. Prior to critiquing this approach it is necessary to first present an understanding of heuristic analysis and to demonstrate the approach presented in the report prepared for the Australian Commission on Safety and Quality in Health Care (Preece, Horswill, Hill, Hewett, & Watson, 2009).

2.3.2. A Heuristic Evaluation of Observation Charts, Where is the Theory?

Horswill et al., (2010) state that in their report for the Australian Commission on Safety and Quality in Health Care entitled: *Human factors research regarding observation charts: Research project overview*, that heuristic analysis of 25 existing observation charts was performed in order to discover usability problems with charts. This evaluation is described in more detail in the report entitled *Heuristic Analysis of 25 Australian and New Zealand Adult General Observation Charts.* In this report it is observed that *vital signs are not always correctly recorded or appropriately acted upon* (Preece et al., 2009, pg. 2) and while they recognise the lack of research pertaining to the design and use of observation charts, they posit that improving the design of observation charts can benefit nurses using the charts. The report cites Chatterjee, et al., (2005) who observed an improvement in nurse's ability

to recognise patient deterioration when using a new observation chart design. This information is used as the justification for their research. Having presented the justification for the research the report goes on to discuss the heuristic analysis of 25 existing observation charts.

Nielsen, (1992) describes heuristic evaluation as:

> *A method for finding usability problems in a user interface design by having a small set of evaluators examine the interface and judge it's compliance with recognised usability principles (the "heuristics").*(Nielsen, 1992, pg. 373)

In the case of the evaluation of the observation charts, the set of heuristics principles employed were based on published HCI research findings. These heuristics were classified using the following headings (Preece et al., 2009, pg. 5-6):

Simple and natural 'dialogue'

- *The aim of any system should be to present exactly the information the user needs (and no more) at exactly the time and place that it is needed.*
- *The system should match the user's task in as natural a way as possible. Operations should be in a sequence that matches the way the user does things if appropriate.*
- *Information that will be used together should be displayed close together.*

Aesthetic and minimalist design

- *The system should not contain information that is rarely needed (as such information competes with relevant information for the user's attention).*
- *The system's graphic design and colour should be carefully considered, e.g.:*
    - *Avoid unrelated elements being formatted in a such a way that they seem to belong together and vice versa (otherwise the user will need more search time) (Gerhardt-Powals, 1996)*
    - *Information presented in the top left of a display normally gets more attention.*
    - *Avoid over-using upper-case text, it attracts attention, but is 10% slower to read than mixed-case text*
    - *Avoid more than seven colours (on a webpage) or the display will look too "busy"*
    - *If colour is to be used, the system requires redundant cues so that colour-blind users are able to use the system with ease.*

Speak the users' language

- *Words, phrases and concepts used should be familiar to the user.*
- *The system should have a good match between the display of information and the user's mental model of the information.*

Minimise the users' cognitive and memory load

- *Reduce the time spent assimilating raw data. Automate unwanted workload, i.e. eliminate mental calculations, estimations, comparisons and unnecessary thinking, to free cognitive resources for high-level tasks.*
- *Bring together lower level data into a higher-level summation if appropriate. Present new information with meaningful aids to interpretation (Gerhardt-Powals, 1996). The system should be memorable.*
- *Users should be able to use the system easily even after a period of not using it (Zhu, Vu, & Proctor., 2005).*
- *The system should be based on a limited number of pervasive rules that apply throughout.*
- *The system should allow the user to rely on recognition rather than recall memory. Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons).*
- *When users are asked to provide input, the system should describe the required format and, if possible, provide an example.*
- *Basic functionality should be understandable in 1 hour.*

Consistency

- *Users should not have to wonder whether different words or actions mean the same thing.*

Prevent errors

- *The system should produce minimal errors. Practice judicious redundancy (Gerhardt-Powals, 1996).*

Precise and constructive error messages

- *Messages should be phrased in clear language and avoid obscure codes (the user should not have to refer to elsewhere, e.g. the manual).*
- *Messages should help the user solve the problem.*
- *Consider multi-level messages; it is possible to use shorter messages that will be faster to read, as long as the user has access to a more elaborate message.*

Help and documentation

- *Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out and not be too large.*
- *Consider different levels of documentation, e.g. short reference cards vs. introductory manual for new users.*

It should be recognised that the purpose of the research communicated in the reports for the Australian Commission on Safety and Quality in Health Care was to develop a single observation chart that outperforms previously designed observation charts in terms of all of the heuristics presented above. This research was necessary in order to take the first step in designing a superior observation chart that would be included as a fundamental component in their AWTTS. The information gathered from this evaluation allowed the group to identify usability issues with charts and also allowed the group to identify design features which resolved some of the usability issues. The research also allowed for the formalisation of design principles for the design of observation charts in the form of the published *Developer's Guide for Observation and Response Charts* (Preece, Hill, et al., 2010). However, Preece et al., (2009) observe the difficulty of meeting of all the heuristic principles described above and also noted some contradictions in the principles. This observation is indicative of a limitation of their approach.

The heuristic evaluation approach employed by Preece et al., adapted multiple HCI references to establish a set of heuristic principles. While the results of this research were positive and the final observation chart produced by the research was found to be more useful than previously evaluated charts, it is the position of this research that the method used to adapt HCI literature to identify the heuristics created a separation of task from theory. Section 2.3.1 posits that design requires knowledge of the problem system. By understanding the problem system, the designer is able to establish priorities in terms of what aspects of the problem system the design focus should be on. For example, considering the heuristic principles presented above, there is no clear indication of which of these principles is most important for the design of an observation chart. Furthermore, it is not clear what aspects of the clinical reasoning process these heuristic principles are designed to support. These observations imply that the literature review method employed by Preece et al.,

resulted in a relatively superficial understanding of the heuristic principles and their impact on the problem system. As such, it can be assumed that a broad but shallow literature review was performed when establishing the heuristic principles for evaluation of the observation charts. Therefore, a deep understanding of the problem system is not presented.

A further issue with the existing AWTTS chart design literature is that there is no indication as to what method was used to discover the heuristic principle sets. Hvannberg, et al., (2007) describe two methods for identifying heuristic principle sets. The first style is a bottom up approach where appropriate heuristics are identified from a larger set, (i.e. synthesised). The second style is heuristics as defined from abstract theories. Issues exist with each method of identifying heuristic sets. When identifying synthesised heuristics a community may establish an accepted heuristic, however, useful details pertaining to the unused heuristics may then be forgotten. When identifying heuristics from abstract theories, the members of the community may not fully comprehend the abstract theory which can lead to ambiguity (Connell & Hammond., 1999; Hornbæk, 2004). Table 2.4 presents an overview of the benefits and limitations of the two methods for identifying heuristic principles. While the approach employed by Preece et al. has not been presented, it appears that the second approach was employed. Again, as a deep explanation of the foundational theories from which the heuristic sets were abstracted from is not presented, it becomes difficult to establish whether the heuristics are true to the original theoretical base.

Method for Identifying Heuristic Principles	Benefits of Approach	Limitation of Approach
Bottom-Up – Heuristics identified from larger sets.	More likely to understand principles.	Useful principles may be forgotten.
Top-Down – Heuristics defined from abstract theories.	Provides deeper understanding of the principle and its intended purpose.	Original theory may not be fully understood.

Table 2.4. Benefits and limitations of methods for identifying heuristic principles.

While this section has presented some concerns surrounding the method for identifying heuristic principles employed by Preece et al. it is clear that the approach employed was appropriate. This can be observed as the design of the observation chart that emerged from this research was evaluated to be more useful than previously evaluated charts. The methods employed were necessary as there was a shallow pool of observation chart design literature and the goal of the research was to identify good design principles for each element of an observation chart. However, if the observation chart design community is to move forward to further improve the design of paper-based and electronically-generated observation charts there is a necessity to change the approach for designing charts. The following section will discuss the necessity to move from a design feature-led approach to a theory-led approach, which will provide a deeper connection between task and theory and will allow further iteration on the good work performed by Preece et al.

2.3.3. Departing from a Design Feature-Led Research Agenda

Section 2.3.2 establishes that some methodological issues exist with the existing AWTTS chart design literature. This stemmed from the observation that the existing chart design literature took a broad and shallow approach to identifying literature pertaining to the design of observation charts. This approach was necessary as there was little observation chart design literature published and there was a necessity to establish useful design features for each functional element of an observation chart. While this approach was appropriate in the case of the development of the AWTTS chart by Preece, et al. (2010), this also presents an opportunity to further discover literature that can contribute towards improving the design of specific features instantiated on an AWTTS chart. This approach would require a change in direction from existing AWTTS chart design literature.

Existing literature takes an approach of evaluating the usability of specific design features instantiated on situated observation charts, therefore identifying the most useful design features. As observed in section 2.3.2, the approach employed thus far for the design of the observation charts for AWTTS systems has been characterised by an absence of foundational theory to explain the design choices and why particular design features are useful. This implies that the research thus far was

likely to have been design feature-led, as opposed to a theory-led approach. In order to embrace a theory-led approach, there is a necessity to formalise knowledge of the problem systems and theories which help to explain the usefulness of design features. Sutcliffe, (2006) made a similar observation and proposed that theory-led design should be a 'grand challenge in HCI'. Sutcliffe observed that it is difficult to formalise the relative contribution of *internalised and tacitly applied theory* and noted that knowledge of how humans perceive and interact with specific design features can help to improve the design of interfaces.

Considering this call for theory-led design, it is useful to consider the heuristic principles developed by Preece et al., (2009) presented in section 2.3.2. These principles were assimilated based on findings from HCI research. While the principles appeared to be useful in terms of facilitating the evaluation of the usability of existing observation charts, it is unclear whether these findings were based on theoretical knowledge or to what extent this theoretical knowledge was considered by the researchers. As this knowledge cannot be obtained from reviewing the literature surrounding the design of the AWTTS chart for the Australian Commission for Quality and Safety in Health Care and Queensland Health, there is a lack of transparency in the research.

This observation raises another issue with the existing AWTTS observation chart design literature. Research that is not transparently presented is analogous to not presenting a deductively valid argument, that is to say an argument *in which the logical connection between premises and conclusion is one of necessity* (Lupia, 2008, pg. 734). A deductively valid argument is generally seen as a superior argument to an inductively valid one, (i.e. *the premise is true, but the conclusion cannot be definitively stated*). From the perspective of the observation chart design for AWTTS, it can be stated that an inductive approach has been followed where design features (i.e. the premise) are found to be useful, but there is no clear connection between the design features and their theoretical underpinnings. Therefore, it becomes difficult to identify the link between the problem system and the design features. If the links between the design features and the theories that explain the problem system had been adequately communicated then it would be

easier to establish a deductive line of reasoning for their design. This connection is also observed in the design science literature which observed a link between observed rigor and procedural transparency (Gleasure et al., 2012; H. K. Klein & Myers, 1999).

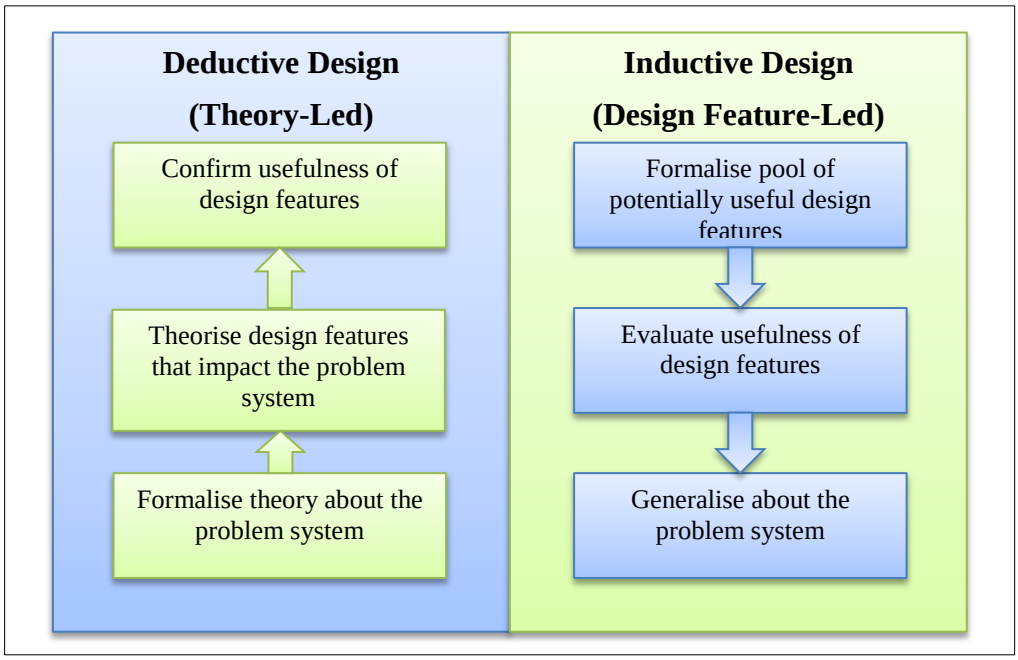


Figure 2.4. Logical flow of theory-led and design feature-led design.

It is unclear as to whether this design feature-led research is a result of a shallow coverage of theory or whether the theory has been covered but has not been formally presented in the literature. An antecedent of this issue with the literature is that it becomes difficult to iterate on the artefact or the design features emerging from the research. Again, if the research was theory-led, rather than design-feature led, it would facilitate communicating an understanding of the problem system and how specific design features were design to affect a required change on the problem system. Having identified a number of issues within the existing pool of AWTTS observation chart design literature, section 2.4 presents a synthesis of the EWS design literature presented in section 2.3 and the issues with observation chart design literature.

2.4. Reconciling Good EWS Design with a Theory-Led Design Approach

In section 2.2, an investigation into good design principles for an early warning system (EWS) was presented. Having established the principles, the Irish HSE's paper-based National Early Warning Score (NEWS) system was considered from the perspective of these principles. The NEWS system is a form of medical early warning system designed to identify patients at risk of deterioration, with these kinds of systems typically being referred to as Aggregate Weighted Track and Trigger Systems (AWTTS). It was established that the NEWS system met a lot of the requirements for good EWS design, however, it was also established that there are potential areas of weakness in the system. These potential weaknesses are hinged on the nature of human error. A system that relies on human accuracy and human cognitive capacity is limited by the nature of human error. Section 2.2 established that an electronic AWTTS could potentially mediate against some issues regarding human error; however, the nature of clinical reasoning for patients relies on the health professional to use their own experiential knowledge and cognitive capacity to make care decisions for patients. In order to minimise the cost of human error it was established that an AWTTS system should be designed to facilitate human decision making rather than trying to replace it. It was then established that in order to design an electronic AWTTS chart that can facilitate clinical reasoning, there is first a necessity to understand the nature of clinical reasoning and what aspects of the clinical reasoning process can be supported by an electronic AWTTS system.

Element	Description
Risk Knowledge	• Are the hazards and the vulnerabilities well known? • What are the patterns and trends in these factors? • Are risk maps and data widely available?
Monitoring & Warning Service	• Are the right parameters being monitored? • Is there a sound scientific basis for making forecasts? • Can accurate and timely warnings be generated?
Dissemination & Communication	• Do warnings reach all of those at risk? • Are the risks and warnings understood? • Is the warning information clear and useable?
Response Capability	• Are response plans up to date and tested? • Are local capabilities and knowledge made use of? • Are people prepared and ready to react to warnings?

Table 2.5. The four elements of good EWS design.

Section 2.3 then presented a critical analysis of AWTTS observation design literature. It was established through a literature review that the pool of AWTTS design literature is quite small, however, the principle source of literature could be traced to a project conducted for the Australian Commission for Quality and Safety in Health Care and Queensland Health. It was established that the group took a Human Factors (HF) approach. The HF design approach was employed to design a chart that was designed based on a heuristic evaluation of 25 other observation charts used in Australia and New Zealand. The heuristic principles that were used to evaluate the observation charts were based on principles established in Human Computer Interaction (HCI) literature. The heuristic evaluation sought to establish the usefulness of specific observation chart features and employed expert evaluators to evaluate the charts based on the heuristic principles identified in HCI literature. It appears that the group employed a broad and shallow literature review to formalise the heuristic principles. It was observed in section 2.3 that this approach was both necessary and successful. This approach was necessary as the usefulness of each design feature instantiated on the charts had to be evaluated to determine which design features to instantiate on the new AWTTS observation chart. The approach was useful as a deeper literature review could have been anti-productive in terms of

slowing down the design process. The approach was ultimately successful as the product of the design process (i.e. the AWTTS chart) was found to be more useful than previously evaluated observation charts.

However, this approach is also a source of the limitations associated with the research. Employing a broad and shallow literature review to identify heuristic principles implies that the foundational theory might not have been utilised correctly. If the theory had been utilised correctly there is a lack of formally communicated research that presents the link between the design features and the underlying theories. Furthermore, as this link is not clearly communicated, it becomes difficult to iterate on any successful design features and it becomes difficult to establish the validity of the research approach employed.

Heuristic Set	Heuristic Principles
Simple and natural 'dialogue'	• *The aim of any system should be to present exactly the information the user needs (and no more) at exactly the time and place that it is needed.* • *The system should match the user's task in as natural a way as possible. Operations should be in a sequence that matches the way the user does things if appropriate.* • *Information that will be used together should be displayed close together.*

Aesthetic and minimalist design	• *The system should not contain information that is rarely needed (as such information competes with relevant information for the user's attention).*
	• *The system's graphic design and colour should be carefully considered, e.g.:*
	  ○ *Avoid unrelated elements being formatted in a such a way that they seem to belong together and vice versa (otherwise the user will need more search time) (Gerhardt-Powals, 1996)*
	  ○ *Information presented in the top left of a display normally gets more attention.*
	  ○ *Avoid over-using upper-case text, it attracts attention, but is 10% slower to read than mixed-case text*
	  ○ *Avoid more than seven colours (on a webpage) or the display will look too "busy"*
	  ○ *If colour is to be used, the system requires redundant cues so that colour-blind users are able to use the system with ease.*

Speak the users' language	• *Words, phrases and concepts used should be familiar to the user.* • *The system should have a good match between the display of information and the user's mental model of the information.*

Heuristic Set	Heuristic Principles
Minimise the users' cognitive and memory load	• *Reduce the time spent assimilating raw data.* • *Automate unwanted workload, i.e. eliminate mental calculations, estimations, comparisons and unnecessary thinking, to free cognitive resources for high-level tasks.* • *Bring together lower level data into a higher-level summation if appropriate. Present new information with meaningful aids to interpretation (Gerhardt-Powals, 1996). The system should be memorable.* • *Users should be able to use the system easily even after a period of not using it* (Zhu et al., 2005). • *The system should be based on a limited number of pervasive rules that apply throughout.* • *The system should allow the user to rely on recognition rather than recall memory. Users should not have to remember information from one part of the system to another (i.e. avoid mental comparisons).* • *When users are asked to provide input, the system should describe the required format and, if possible, provide an example.* • *Basic functionality should be understandable in 1 hour.*
Consistency	• *Users should not have to wonder whether different words or actions mean the same thing.*
Prevent errors	• *The system should produce minimal errors. Practice judicious redundancy (Gerhardt-Powals, 1996).*
Precise and constructive error messages	• *Messages should be phrased in clear language and avoid obscure codes (the user should not have to refer to elsewhere, e.g. the manual).* • *Messages should help the user solve the problem.* • *Consider multi-level messages; it is possible to use shorter messages that will be faster to read, as long as the user has access to a more elaborate message.*

Heuristic Set	Heuristic Principles
Help and documentation	• *Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out and not be too large.* • *Consider different levels of documentation, e.g. short reference cards vs. introductory manual for new users.*

Table 2.6. The heuristic set for evaluating usability issues of observation charts.

Having established the issues with the Irish HSE's NEWS system from the perspective of good EWS design and identified issues with the existing AWTTS chart design literature, the purpose of this section is to reconcile the observations made in section 2.2 and 2.3. In order to do this it is useful to present an analysis of the NEWS chart from the perspective of the four elements of good EWS design originally presented in section 2.2.1. (Presented in Table 2.5) and the heuristic principles for evaluating the utility of AWTTS chart design presented in section 2.3.2 (presented in Table 2.6).

Both Table 2.5 and Table 2.6 represent evaluation criteria for assessing the usefulness of EWS. Table 2.5 presents criteria for evaluating an EWS from a holistic perspective, with Table 2.6 presenting principles for evaluating the quality of the interaction between the user and the system. While both of these approaches utilise differing principles for evaluation, it is useful to analyse the principles to see whether there are areas of overlap. Similar to section 2.2.2, where the NEWS AWTTS was considered from the perspective of the four elements for good EWS design, the following sections will consider the set of heuristic principles presented in Table 2.6 from the perspective of the four elements of good EWS design presented in Table 2.5.

2.4.1. Risk Knowledge

- Are the hazards and the vulnerabilities well known?
- What are the patterns and trends in these factors?
- Are risk maps and data widely available?

The *Risk Knowledge* element is concerned with systematically collecting data, establishing patterns associated with this data and ensuring that this data is widely available to users.

It should be noted that some tasks associated with risk knowledge are not relevant to the design of an observation chart. For example, the work of identifying correlations between vital signs recorded and potential patient deterioration (i.e. *what are the patterns and trends*) is conducted by researchers who analyse vital sign data in an effort to identify core-morbidity factors (Jarvis et al., 2013). Furthermore educating nurses regarding this knowledge (i.e. *are the hazards and vulnerabilities well known)* is also not the purpose of an interface such as an observation chart.

Having established these limitations of observation charts, it is important to note that the design of any interface should to be able to support this knowledge. This is consistent with the observations in section 2.4, where it was established that an artefact being designed for a specific problem system should incorporate knowledge of the problem system into the design of the artefact. As such, it can be observed that the heuristic *"speak the users' language"* and the following principle is relevant to the *Risk Knowledge* element of an observation chart design:

- The system should have a good match between the display of information and the user's mental model of the information.

By presenting information in a manner that forms a good match between the display of information and the user's mental model of the information, it minimises the cognitive cost of assimilating data (Purchase andrienko, Jankun-Kelly, & Ward., 2008). In order to establish these mental models an understanding of the patterns and trends and the hazards and vulnerabilities must be formalised. Once formalised, this knowledge can be considered and methods for supporting this information and the mental models associated with this information can be incorporated into the design of the observation chart.

2.4.2. Monitoring and Warning Service

- Are the right parameters being monitored?

- Is there a sound scientific basis for making forecasts?
- Can accurate and timely warnings be generated?

Monitoring and Warning Service is concerned with ensuring that the correct parameters are continuously being monitored and that a timely and accurate warning message can be generated based on the parameters being monitored. Once generated, the warning message must then be communicated with the relevant parties. While the parameters being monitored have been previously defined based on scientific research, there is an emphasis for the design of the interface/observation chart to ensure that accurate and timely warnings can be generated. Considering the heuristics principles presented in Table 2.6, it can be stated that the following heuristic principles are relevant to supporting *monitoring and warning service.* From the '*prevent errors'* heuristic:

- The system should produce minimal errors.
- Practice judicious redundancy

A system that produces errors implies that the system should be designed to minimise the cost of human error. It was established in section 2.2.4, that human judgement is an important in the clinical reasoning process and that a medical EWS should not replace human judgement, instead it should seek to augment or support it. As such, an observation chart or an AWTTS system should be designed in a manner which reduces human input that is not judgement based. Judicious redundancy seeks to ensure that errors are minimised through grouping relevant data together and including only relevant information to the user (Molich & Nielsen, 1990).

2.4.3. Dissemination and Communication

- Do warnings reach all of those at risk?
- Are the risks and warnings understood?
- Is the warning information clear and useable?

This element is concerned with ensuring that the warning message from an EWS is adequately communicated with the appropriate people who should act on the

warning. From the perspective of the heuristic set presented in Table 2.6, a number of heuristics can be associated with this element.

From the *aesthetic and minimalist design* heuristic:

- The system's graphic design and colour should be carefully considered.

This is relevant as the aesthetic and minimalist design is intended to ensure that the warning message and the information presented on the chart is as easy to read as possible, thus ensuring that warning service is understood (Carpendale, 2008). From the *speak the user's language* heuristic:

- Words, phrases and concepts used should be familiar to the user.
- The system should have a good match between the display of information and the user's mental model of the information.

Can also be interpreted as; features that would facilitate communicating a warning message to the user. From the *'precise and constructive error messages'* heuristic:

- Messages should be phrased in clear language and avoid obscure codes (the user should not have to refer to elsewhere, e.g. the manual).
- Messages should help the user solve the problem.
- Consider multi-level messages; it is possible to use shorter messages that will be faster to read, as long as the user has access to a more elaborate message.

Each of the heuristics presented above are focused on ensuring that the physical design of the chart and the language presented on the chart make sure that the warning message is disseminated and communicated as clearly as possible.

2.4.4. Response Capability

- Are response plans up to date and tested?
- Are local capabilities and knowledge made use of?
- Are people prepared and ready to react to warnings?

Response capability is concerned with ensuring that having communicated the early warning message that the affected stakeholders can then react in an appropriate to the

threat. This element of the design of early warning systems is reliant on education and preparedness. While this is an important component of an early warning system design, this does not directly concern the design of an interface for recording and presenting parameters for the early warning system.

2.4.5. An Approach for Facilitating Clinical Reasoning Processes through Theory-Led Design

Sections 2.4.1 to 2.4.4 presented an analysis of how the HCI heuristic principles formalised by Preece et al. for the evaluation of the usefulness of observation charts maps to the design principles for good early warning systems. Table 2.7 presents an overview of the findings from these sections.

Element	Paper-Based NEWS Chart	Observation Chart Heuristic Sets
Risk Knowledge	• Are the hazards and the vulnerabilities well known? • What are the patterns and trends in these factors? • Are risk maps and data widely available?	• Simple and minimal design.
Monitoring & Warning Service	• Are the right parameters being monitored? • Is there a sound scientific basis for making forecasts? • Can accurate and timely warnings be generated?	• Prevent errors.
Dissemination & Communication	• Do warnings reach all of those at risk? • Are the risks and warnings understood? • Is the warning information clear and useable?	• Aesthetic & minimal design. • Speak the user's language. • Minimise cognitive cost. • Consistency. • Precise and constructive error message.

Element	Paper-Based NEWS Chart	Observation Chart Heuristic Sets
Response Capability	• Are response plans up to date and tested? • Are local capabilities and knowledge made use of? • Are people prepared and ready to react to warnings?	• Help & documentation.

Table 2.7. NEWS chart from the perspective of the four elements of good EWS design.

What can be observed from reading Table 2.7 is that the HCI heuristic principles can support each of the 4 elements of good EWS design to some extent, however, the primary focus of these HCI heuristic principles appears to focus on the dissemination and communication of information. This focus is logical as a chart primarily serves 2 functions; the first is to allow an individual to record contextual information about the patient: and second to act as a means of presenting the information in a useful way. A chart is not designed to educate the user regarding *risk knowledge*, there is an assumption that the individual nurse reading the chart already has built knowledge regarding hazards and vulnerabilities from experiential learning. Previous research in the development of the algorithms for early warning scores has been conducted and any further developments in this research will inform the *monitoring & warning service* aspect of AWTTS design. Training, escalation plans and policy will then inform the *response capability* element of the AWTTS design. As such, it is logical that the direction for the design of an AWTTS interface should concentrate on the *dissemination & communication* element of EWS design.

Further evidence of the necessity to consider the design for *dissemination & communication* can be observed in section 2.2.2.3, where it was established that this element of the design of the Irish HSE's NEWS system is highly dependent on human cognitive capacity. As such, any element that relies on human competency is also subject to potential failures resulting from human errors. Sections 2.2.4 and 2.2.5 established that it was necessary to follow a design process that would not remove human judgement as an important component in the clinical reasoning process and instead would focus on designing an interface that could facilitate

clinical reasoning processes associated with making care decisions for patients. It was observed in section 2.3.3, that in order to achieve the goals of this research for designing an interface that facilitates clinical reasoning there is a necessity to follow a theory-led design approach that will incorporate the knowledge and theories that will guide the design of the observation chart interface.

2.5. Conclusion

Chapter 1 presented an overview of the background of this research project, an introduction to the problem system and the research objective of this study. The objective of the research was defined as:

> *To design, implement and evaluate a set of design principles, which when instantiated, have a positive impact on* nurses *ability to process information presented on an electronically generated AWTTS chart. The set of design principles will be referred to as the framework for REVIEWS.*

The purpose of this chapter has been to present an overview and analysis of literature pertinent to achieving the research objective. Section 2.2 established that an AWTTS is a form of Early Warning System (EWS) and presented an investigation into design principles for designing a good EWS. This investigation identified the *four elements of people-centred early warning systems*, these elements present a checklist of design principles that an early warning system should meet in order to achieve good design. The four elements were concerned with: *risk knowledge, monitoring & warning service, dissemination & communication and response capability.*

Having formalised that these elements were a necessary part of designing an EWS, section 2.2.2 presented a decomposition of an AWTTS from the perspective of these four elements. The AWTTS in question was the Irish Health Service Executives (HSE) National Early Warning Score (NEWS) system. This decomposition established that each of the four elements were adequately addressed in the design of the NEWS system. However, section 2.2.3 presented an analysis of potential weaknesses in the system. These weaknesses were concerned with the systems reliance on human competency. In any process that relies on human competency,

there is also a capacity for human error to negatively impact the usefulness of the system. In section 2.2.5 it was established that while human error can have a negative impact, the reality of working in a complex system such as a hospital when making care decisions for a patient, requires that human decision makers have an input in the care decisions made for a patient.

Considering the importance of the human decision maker in the process of making care decisions for patients, section 2.2.5 explored decision support in information systems literature. This established that the process of using data presented on an observation chart to make care decisions is rarely a case of simply applying knowledge to a problem and is instead a sense-making activity where individuals perform information processing to help structure complex problems. This process is similar to that of naturalistic decision making, where it was established that decision types vary, a blend of intuition and analysis is employed, decisions are context dependent and that decision making is a dynamic process (Lipshitz, 1995). Considering the complexity of the decision making process for care decisions, it can be stated that; prior to designing an improved AWTTS chart there is a necessity to develop a further understanding of how nurses make decisions using AWTTS charts.

Having investigated the design of early warning systems and analysed this information from the perspective of an AWTTS, section 2.3 then presented a critical analysis of existing AWTTS chart design literature. It was established that a small pool of chart design literature exists, with the principle source of literature emerging from a research project for the Australian Commission on Safety and Quality in Health Care (ACSQHC). It was established that the method employed for establishing useful design principles for AWTTS charts was by evaluating the usefulness of design features instantiated in existing observation charts. This research used heuristic evaluation where heuristic sets were established through identifying suitable heuristic principles in Human Computer Interaction (HCI) literature. While the method employed gave useful results, a number of criticisms were made regarding the methodology used to evaluate the observation charts and how the method was communicated.

A consequence of the methodological issues identified in section 2.3 was the observation that there was a potential disconnect between the theoretical foundations of the HCI literature and the heuristic principles identified by the group researching for the ACSQHC. It was established in section 2.3.3, that in the case of the study conducted for the ACSQHC, the research appeared to be design feature-led. That is to say, that the research began with design features and evaluated the utility of these features. This approach is considered to be non-optimal as there is no clear logical link between the premise (theoretical knowledge) and the conclusions of the evaluation. Rather than starting with design features, it is optimal for a design approach to begin with the theory and to then establish design features which utilise this knowledge. This creates a clear connection between the premise of a design feature and the results of the evaluation of the design feature; furthermore if this link is adequately communicated it facilitates iterative design improvements on the design feature or can allow for the design feature to be interpreted in a different way potentially leading to improved designs.

Section 2.4 reconciled the findings from the literature reviewed in sections 2.2 and 2.3. This section ultimately established from an information systems perspective, that the focus for the design of an electronic observation chart should be on the *dissemination & communication* element of an early warning system. It was established that this element is most likely to suffer from issues associated with human error and this is reflected in the focus placed on the previous research in formalising design features that support this element. Having critically analysed the literature pertaining to the design of AWTTS charts in this chapter, there is now a necessity to establish a research design that can address these findings of this chapter. This research design will be presented in chapter 3.

Chapter 3 : THE METAPHYSIC AND METHODOLOGICAL CONSIDERATIONS FOR THIS RESEARCH

3.1. Introduction

The purpose of this chapter is to present the research approach for this study and to present the philosophical foundations which have guided the design of the research approach. This research employs a Design Science Research (DSR) approach, which typically takes the form of a *design, build, evaluate* process. When explaining the *design, build, evaluate* process it is useful to present a definition of the term *design.* Ralph and Wand, (2009) define design as:

> *(noun) a **specification** of an **object**, manifested by some **agent**, intended to accomplish **goals**, in a particular **environment**, using a set of **primitive components**, satisfying a set of **requirements**, subject to some **constraints**.*
>
> *(verb, transitive) to create a design, in an environment (where the designer operates)*
>
> (Ralph & Wand, 2009, pg. 108)

This definition presents the idea of design as a creative process where knowledge of the environment, the constraints, the user requirements, the artefact specification and the goals of the artefact are interrelated. This implies that if the design knowledge for one of these components has not been established then the design of the final artefact will be suboptimal. Furthermore, without rigorously and transparently formalising this design knowledge, it becomes difficult to repeat the design; therefore it becomes difficult to iteratively improve on the artefact.

It is the position of this research that without developing an understanding of the constructs in Ralph and Wand's definition the design of the research would be ambiguous. The research would therefore not meet the minimum requirements of scientific research as the research would not be rigorous, repeatable or transparent and any findings would not be generalisable. Having established the necessity for a DSR approach that is rigorous, repeatable and transparent the following chapter

presents the underpinning philosophical perspective of the research and a research approach that is rigorous, repeatable, transparent and produces generalisable knowledge.

3.2. Establish the Philosophical Foundations for This Research

Prior to presenting the research approach employed for this study, it is necessary to establish the philosophical foundations for this study. The three mains strands of philosophical thought that impacts research are *ontology*, *epistemology* and *methodology*. The methodology chosen to collect empirical data during a research effort is directly impacted by the research's ontological and epistemological perspective. While there is not a linear interaction between these philosophical perspectives, it is useful to present the three strands in the order of 1) Ontology, 2) Epistemology and 3) Methodology. The reasoning for this will be explained in the following sections. The method for data collection deployed for this research is described in section 3.5.3, with this section presenting a brief summary of the research's understanding of ontology and epistemology.

3.2.1. Ontology

When discussing philosophical perspectives of scientific research, ontology is typically the first to be discussed. Ontology has been described as the branch of philosophy that is concerned with *the science of what is, of the kinds and structures of objects, properties, events, processes and relations in every area of reality* (Smith, 2008, pg. 1). That is to say that ontology is concerned with *what is out there to know* (Grix, 2002, pg. 175). Guba & Lincoln, (1994, pg. 108) observe that ontology is concerned with the *form and nature of reality and, therefore, what is there that can be known about it?* Information systems research can be considered to be in a unique position, due to it being a *discipline that is at the intersection of knowledge about the properties of physical objects (machines) and knowledge of human behaviour* (Gregor, 2006, pg. 614). This implies that the focus of IS research can be centred on the design of a system to perform a required function and the technical knowledge that emerges from such research, but it is also acceptable for the research to focus on how interaction with information systems impacts human behaviour.

Having established that IS research is in a unique position in that it can focus on the physical properties of an object or it can focus on developing knowledge about how human behaviour is affected by information systems, a question begins to emerge regarding the differing perspectives. This question requires the researcher to consider the philosophical perspective of the research or the researcher's paradigmatic position. Guba & Lincoln, (1994, pg. 108) describe a paradigm as *a set of basic beliefs (or metaphysics) that deals with ultimates or first principles. It represents a worldview that defines, for its holder, the nature of the "world" the individual's place in it and the range of possible relationships to that world and its parts*. This description of paradigms implies that one's perspective of reality and the nature of reality impact the types of theory that one can produce. Popper, (1978) posits that there are three realities that one can begin to understand the world from.

World	Underlying Assumptions
World 1	*The world that consists of physical bodies, of stones and stars; of plants and of animals; but also of radiation and of other forms of physical energy…*
World 2	*The mental and psychological world, the world of our feelings and pain and of pleasure, of our thoughts, of our decisions, of our perceptions and our observations; in other words, the world of mental or psychological states or processes or of subjective experiences.*
World 3	*The world of the products of the human mind, such as languages; tales and stories and religious myths; scientific conjectures or theories and mathematical constructions; songs and symphonies; paintings and sculptures…. Many of the objects belonging to world 3 being at the same time to the physical world 1.*

Table 3.1. Adapted from Popper's three worlds. Source (Popper, 1978, pg. 143-144)

Popper argues that products of a physical world can be manifested or instantiated as physical objects that belong to world 1, however, these products can be manifested in a number of ways. Take for example the text that an author produces to make a book. This text is a product of the mind; however, it may be instantiated in a hard-back, a paper-back, a special edition or maybe a revised edition. While these types of

physical books are all different, the product of the human mind (*the text*) is the same object. Further to this, while a text may be a product that originates from one's mind, the same text can be interpreted differently by each reader. Again consider a book such as the bible, while many strands of religion have emerged based on interpretations of the bible, the bible itself as a text has not changed. Therefore, a product that originates from world 3 can be instantiated in world 1 and can have a subjectively different reality in world 2. Popper's three worlds in essence represent three differing paradigmatic perspectives.

Two examples of ontological positions include; *objectivism* and *constructivism.* Objectivism can be broadly defined as *an ontological position that asserts that social phenomena and their meanings have an existence that is independent of social actors,* that is to say that reality is something tangible and that there is a "real" measurable reality. Constructivism then asserts *that social phenomena and their meanings are continually being accomplished by social actors. It implies that social phenomena and categories are not only produced through social interaction but that they are in a constant state of revision* (Grix, 2002, pg. 177). This implies that reality cannot be objectively measured and instead considers reality to be something that is socially constructed (Bryman, 2012). These are important considerations to reflect on, as one's ontological position of *what is out there to know* and in what world one places oneself in then impacts the type of theory that they can hope to develop. These metaphysics considerations are important to observe prior to establishing the methodology for scientific research. Furthermore, this implies that one's perspective on what is out there to know has a further impact on how one can perform research. Grix, (2002) demonstrates the nature of the directional relationship between ontology, epistemology and methodology by presenting the interrelationships between the building blocks of research in Figure 3.1

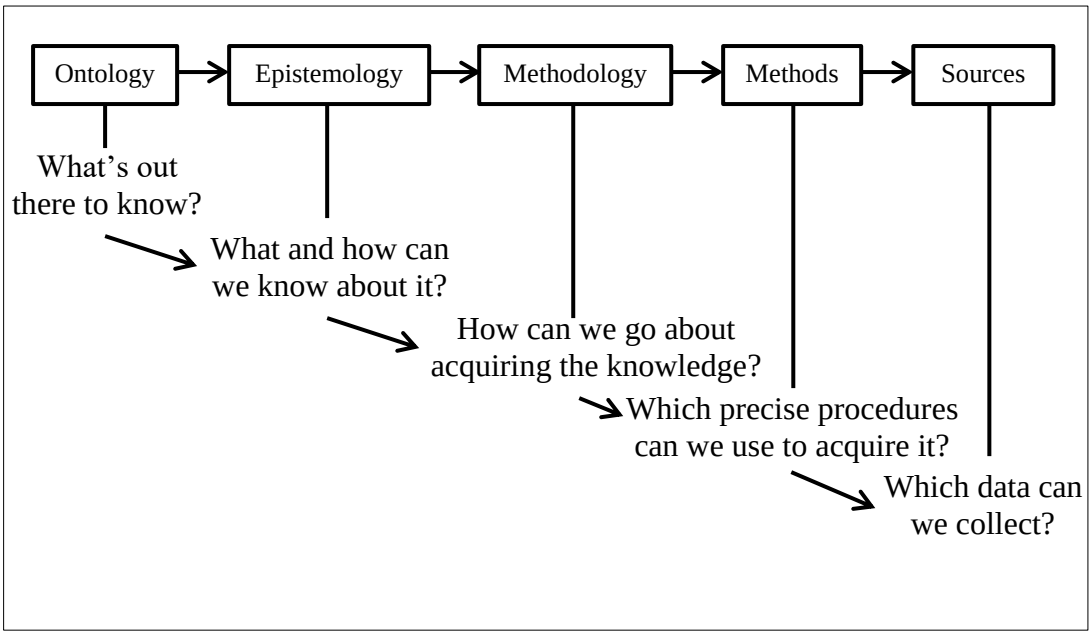


Figure 3.1. The interrelationship between the building blocks of research. Source (Grix, 2002, pg. 180)

Figure 3.1 presents a parsimonious representation of the relationships amongst the philosophical perspectives of research and methodology. The relationships are simplified in this figure, it remains a useful demonstration of the impact that taking a particular paradigmatic perspective has on different strands of philosophy. The following sections will present an understanding of epistemology and will then describe some of the important paradigms employed in IS research. Once this research has situated its paradigmatic perspective, appropriate methodological choices can then be discussed.

3.2.2. Epistemology

As per Figure 3.1, epistemology can be described as *how and what can be known* about theoretical knowledge (Grix, 2002). Gregor, (2006, pg. 612) posits that epistemological questions ask: *how is theory constructed? How can scientific knowledge be acquired? How is theory tested?* Hirscheim, (1985, pg. 188) reflects Gregor's position, by stating that *epistemology refers to our theory of knowledge; in particular how do we obtain 'valid' knowledge.*

In order to present an understanding of these questions it is useful to view research from a paradigmatic perspective as either positivist or interpretivist. While these do

not represent the full spectrum of epistemological perspectives, it is useful to present them in order to demonstrate this research's understanding of epistemology.

3.2.2.1. Positivist Perspective

Kolakowski, (1993, pg. 2) asserts that positivism is characterised by a mode of thinking whereby, *it does not prejudge* how an individual arrives at a position or where this position comes from, instead a procedural series of *rules and evaluative criteria* are applied to these positions. This corresponds to the principle of falsification as per Popper, (1963, pg. 5) who states that *every genuine test of a theory is an attempt to falsify it or to refute it. Testability is falsifiability.* Hirscheim, (1985), identified 5 pillars of positivist research

Pillar of Positivism		Description
I.	*Unity of the scientific method*	The methods of acquiring valid knowledge should be the same for all tests of a theory.
II.	*Search for humean causal relationships*	There should be regularity and causal relationships amongst the constructs being studies.
III.	*Belief in empiricism*	Only objective data is valid.
IV.	*Science (and its process) is value-free*	The methodology can have no bearing on the results obtained.
V.	*The foundation of science is based on logic and mathematics*	Mathematics provides a universal language to allow us to understand phenomena.

Table 3.2. Five Pillars of Positivist Science, adapted from (Hirscheim, 1985)

This type of theory testing is known as a hypothetico-deductive approach, that is to say *theories can be tested* insofar as observational hypotheses can be deduced from them and compared to relevant empirical data (Bechtel, 2013; S. T. March & Smith, 1995). This form of scientific inquiry requires mathematic or quantitative falsification of theory and has been traditionally viewed as the queen of sciences principally due to the thorough requirements to attain "valid" knowledge (Guba & Lincoln, 1994). Considering Grix's position that there is a directional relationship

between ontology and epistemology it is logical to suggest that there is a direct link between an *objectivist* ontological position and a *positivist* epistemological position.

3.2.2.2. Interpretivist Perspective

While positivist research has traditionally dominated accepted scientific research interpretivist research has emerged as a legitimate approach for IS research (H. K. Klein & Myers, 1999). Interpretivist research places people in their social context and is concerned with the uniqueness of a particular situation (Kaplan & Maxwell., 2005). An epistemological position that accepts subjective data as being valid allows for greater opportunity to understand the perceptions that social individuals have of their own activities (Hussey & Hussey, 1997). In an effort to present a fundamental understanding of interpretivist research, (Niehaves, 2007), identified 7 principles of interpretive research.

Principles		Description
I.	*Fundamental Principle of the Hermeneutic Circle*	All human understanding is achieved by iterating between considering the interdependent meaning of parts and the whole that they form.
II.	*Principle of Contextualization*	Requires critical reflection of the social and historical background of the research setting so that the intended audience can see how the current situation under investigation emerged.
III.	*Principle of Interaction Between the Researchers and the Subjects*	Requires critical reflection on how the research materials (or 'data') were socially constructed through the interaction between researchers and participants.
IV.	*Principle of Abstraction and Generalization*	Requires relating the idiographic details revealed by the data interpretation through the application of Principles 1 and 2 to theoretical, general concepts that describe the nature of human understanding and social action.

Principles		Description
V.	*Principle of Dialogical Reasoning*	Requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings.
VI.	*Principle of Multiple Interpretations*	Requires sensitivity to possible differences in interpretations among the participants, as expressed typically in multiple narratives or stories of the same sequence of events under study.
VII.	*Principle of Suspicion*	Requires sensitivity to possible "bias" and "systematic distortions" in the narratives collected from the participants.

Table 3.3. Principles for interpretive field studies in IS (Niehaves, 2007) adapted from (H. K. Klein & Myers, 1999)

While a logical directional relationship can be observed between an *objectivism* ontological position and a *positivist* epistemological position it is also logical to assume that there is a logical directional relationship between constructivism ontology and *interpretivist* epistemology. Table 3.4 presents the logical relationship between epistemology and ontology as identified thus far.

Questions	Objective "Real" Reality	Subjective "Socially Constructed" Reality
What's out there to know?	**Objectivism** *- Phenomena have an existence that is independent of social actors.*	**Constructivism** *- Phenomena and categories are produced through social interaction and are in a constant state of revision.*
How can we know about it? (Attain valid knowledge)	**Positivism** *- Only objective data is valid.* *- The methodology has no bearing on the results obtained.* *- The methods of acquiring valid knowledge should be the same for all tests of a theory.*	**Interpretivism** *- Requires sensitivity to possible differences in interpretations among the participants.* *- Requires critical reflection on how the research materials (or 'data') were socially constructed.* *- Requires sensitivity to possible "bias" and "systematic distortions" in the narratives collected.*

Table 3.4. Logical relationship between ontology and epistemology.

While a logical relationship can be established between objectivism and positivism and constructivism and interpretivism, the logical directional relationship between epistemology and methodology is less direct. Consider Niehaves' principles for interpretive field studies (*see Table 3.3*). While the principles are useful for describing how theory is utilised and how findings should be validated it does not present any methodological considerations. This is an important observation to note as while traditional positivist research denies the validity of subjective knowledge, interpretivist research is not restrained in the same manner (Myers, 1997). While quantitative methods can be employed to present more in depth explanations of variance in relationships among social-constructs qualitative data can provide richer data regarding process theories and possible explanations of why outcomes occur (Kaplan & Duchon, 1988; Markus & Robey., 1988). In order to explore this relationship in more detail there is first a necessity to present an understanding of methodology.

3.2.3. Methodology and the Emergence of Post-Positivism

The terms *methodology* and *method* are often mistakenly used interchangeably. While method refers to the techniques that can be used to analyse data (Blaikie, 2009; Grix, 2002), a methodological question asks: '*how can the researcher find out what they believe can be known?*' (Guba & Lincoln, 1994). This understanding of methodology therefore allows for a logical extension of the directional relationship between ontology, epistemology and methodology. As noted in section 3.2.2.2, it was observed that methodological questions are constrained by the researcher's epistemological and ontological position. It was noted that while a traditional positivist perspective dismisses the use of subjective data as 'valid' data, an interpretive perspective can use both objective or quantitative data as well as subjective qualitative data as valid data.

This chapter has thus far employed a seemingly polar perspective to present paradigmatic perspectives, with these paradigms allowing for either objective or subjective views of reality. However, while this has been useful for presenting an understanding of ontology and epistemology this way of thinking does not apply to methodological perspectives. In order to demonstrate this the post-positivist

epistemological position should be considered. The post-positivist perspective emerged as a critique of traditional positivism. As noted in Table 3.4, positivism requires that *the methodology can have no bearing on the results obtained.* This contradicts what emerged from quantum theory, where it was observed that *the explanation of the behaviour of a particle depends in significant part on the vantage point from which it is observed* (Fischer, 1998, pg. 131), therefore implying that reality depends on where you see it from. Post-positivism therefore encourages the use of subjective data to allow for reflection on the data gathering approach (methodology) employed, in order to assure 'valid' data has been collected.

Post-positivist research therefore signals an *endorsement of epistemological and methodological diversity* (Lapid, 1989, pg. 243), with it attempting to transcend inconsistencies of traditional interpretivist and positivist research (M. L. Smith, 2006). While the epistemological perspective does not negate the utility of quantitative or qualitative methodologies, it does imply that a mix of both methodologies can be useful to help explain data collected. While interpretive research has always allowed for a mix of both quantitative and qualitative data to help to explain a socially constructed reality, a post-positivist position allows for the use of quantitative and qualitative data to help explain phenomena that occur in an independent reality. By employing this position, post-positivist research can help to address a research-rigor gap associated with traditional positivist and interpretivist research by employing a multilevel approach to causal analysis (Carlsson, 2006; Hodgkinson & Rousseau, 2009; Straub & Ang, 2008) This is reflected in Table 3.5.

	Positivism	Interpretivism	Post-Positivist
Ontology	Phenomena have an existence that is independent of social actors.	Phenomena and categories are produced through social interaction and are in a constant state of revision.	Phenomena have an existence that may be dependent on the social actors.
Epistemology	Only objective data is valid. The methodology has no bearing on the results obtained. The methods of acquiring valid knowledge should be the same for all tests of a theory.	Requires sensitivity to possible differences in interpretations among the participants. Requires critical reflection on how the research materials (or 'data') were socially constructed. Requires sensitivity to possible "bias" and "systematic distortions" in the narratives collected.	Requires sensitivity to subjective perspective that may impact reality. Requires critical reflection on how the research materials (or 'data') were socially constructed.
Methodology	Quantitative only.	Typically qualitative, mixed-methods also useful.	Quantitative or Mixed-Methods.

Table 3.5. Methodological considerations for epistemological paradigms

Critical Realism (CR) is an example of a paradigmatic perspective that leverages post-positivistic ontological, epistemological and methodological principles (Carlsson, Henningsson, Hrastinski, & Keller, 2011; Wynn & Williams, 2012). While many of the considerations of a post-positivist perspective have been discussed, a CR perspective also implies further ontological, epistemological and methodological concerns. From an ontological perspective reality exists independently (Reed, 2001), with it consisting of *structures, mechanisms, events and experiences; emergent powers dependent upon but not reducible to lower-level powers; and an open systems perspective* (Wynn & Williams, 2012, pg.790). The position that reality exists as an 'open system' is important to note as it has an

impact on the type of 'valid' data that exists and how this data can then be collected and analysed.

As previously discussed, a post-positivist paradigm requires reflection on where the data comes from. This is consistent with CR, however, CR also requires a perspective of reality as an open system, it needs to be observed that reality is beyond our control and that changes to any element of this open-system will change the structure of the system itself and will impact other elements within the system (Bhaskar, 1998). Considering the complexity of reality CR holds that it is unlikely that all of the preceding mechanisms that lead to an outcome can be observed. As such, CR seeks to explain a set of events or mechanisms that are likely to have produced specific events (Bhaskar, 1998; Wynn & Williams, 2012), with an explanation specifying the elements that lead to said event (Robert K. Yin, 2002). This observation has a further impact on how data can be collected with case studies being observed as the optimal methodology for allowing the researcher to identify complex mechanisms that possibly lead to an event (Dobson, 2001; Easton, 2010; Harrison & Easton, 2004). While a case study may give the best opportunity for the researcher to be able to identify mechanisms, it should be noted that mechanisms are not necessarily empirically observable (Bhaskar, 2013), however, it may be possible to observe it's effects (Wikgren, 2005; Wynn & Williams, 2012). Furthermore, it may be possible to identify multiple explanations for a given event, in such a case the researcher should perform *judgement rationality* to select the most likely possible explanation (Groff, 2004). The following description of CR provides a useful overview of the elements of CR as described thus far in this section:

> *First, the critical realist is never content just with description, whether it is qualitative or quantitative. No matter how complex a statistical analysis or rich an ethnographic interpretation, this is only the first step—CR wants to get beneath the surface to understand and explain why things are as they are, to hypothesize the structures and mechanisms that shape observable events. Second, CR recognizes the existence of a variety of objects of knowledge—material, conceptual, social, psychological— each of which requires different research*

methods to come to understand them. And, CR emphasizes the holistic interaction of these different objects (Mingers, 2002, pg. 302).

3.2.4. Arriving at Critical Realist Philosophical Perspective

As noted in section 3.2.1 Guba & Lincoln, (1994, pg. 107) describe paradigms as *a set of basic beliefs (or metaphysics) that deals with ultimates or first principles. It represents a worldview that defines, for its holder, the nature of the "world" the individual's place in it and the range of possible relationships to that world and its parts.* The previous sections attempted to present ontology based and epistemology based paradigms in an attempt to demonstrate the different considerations that each paradigm entails. As Figure 3.1 demonstrates a paradigm must ask questions of: *What is there to know? How can we know about it?* and, *How can we acquire knowledge about it?* Table 3.5 presents a brief summary of three epistemological paradigmatic perspectives and presents a brief overview of what considerations these positions entail.

Section 3.2 has thus far presented two seemingly polar ontological perspectives in *objectivism* and *constructivism and* then presented two seemingly polar epistemological paradigms in *positivist* and *interpretivist*. When discussing methodological considerations it was observed that paradigms are not necessarily neatly delineated with regards to ontology, epistemology and methodology. In fact it was observed that criticisms of a traditional positivist approach demonstrated that reality can sometimes be dependent on the subjective perspective of the viewer. This lead to a post-positivist paradigm that ontologically understands that there is a real tangible reality, but that it is sometimes necessary to employ subjective methods of data collection to allow us to understand phenomena. This discussion demonstrates that throughout the history of scientific discourse criticism of paradigms have emerged, with these criticisms often leading to the emergence of new paradigms.

Having presented an understanding of philosophical paradigms, it is now possible to establish the paradigmatic perspective for the research presented in this thesis. Following the logic of this chapter thus far, the following questions will be asked: *What is out there to know*? (Ontology), *What and how can we know about it?* (Epistemology) and *How can be acquire knowledge about it?* (Methodology)

What is out there to know?	• Phenomena have an existence that may be dependent on the social actors.
What and how can we know about it?	• Requires sensitivity to subjective perspective that may impact reality. • Requires critical reflection on how the research materials (or 'data') were socially constructed.
How can we acquire knowledge about it?	• Mixed-Methods.

Considering the answers to these questions, it is now possible to state that the philosophical paradigm that this research will arrive at is a post-positivist critical realist (CR) one. This position will therefore have an impact on the types of theory that this research will establish how valid knowledge can be attained, as well as the methods that can be employed to collect the data. Having established a C position, this chapter will now consider how the objective of this research can be achieved through employing a CR approach.

3.3. Focusing the Lens: Approach for Formalising a Theory of Design and Action

As established in chapter 1, the objective of this research is *to* i*nvestigate and produce a set of design principles, which when instantiated, have a positive impact on* nurse*s ability to process information presented on an electronically generated vital sign chart. The set of design principles will be referred to as the framework for REVIEWS.* In order to achieve this objective there is a necessity to consider it from a philosophical perspective. The questions we need to ask are: *what is out there to know* (Ontology), *how can we know about it (Epistemology)?* and *how can we*

acquire knowledge about it (Methodology)? As observed in section 3.2, questions of ontology and epistemology relate to how we see the world and how we can know about the world. Popper, (1959) suggests that there needs to be a fundamental understanding of these questions prior to embarking on the task of scientific discovery. Swedberg, (2012) posits that in order to begin this task of scientific discovery, there is a process that is followed. The first step is that of *theorizing*, which Swedberg describes as the creative process of establishing a priori theory. A prior theory suggests that; through the application of previous knowledge an initial theory can be developed. That is not to say that theorizing produces theory in fact the product of theorising is rarely a valid theory, however, what emerges from theorising may be the building blocks that allow research to begin to develop full-blown theories (Sutton, Staw., & Weick, 1995). As such, in order to formalise what kind of theories may be produced by this research it is useful to present an understanding of what theory is.

Establishing a formal definition of what theory is has proved to be a difficult task. Sutton & Staw, (1995) present a perspective that research should aim to build strong theory and present what theory is not. They posit that:

- Theory is not a reference to a theory,
- Theory is not data,
- Theory is not a list of variables or constructs,
- Diagrams are not theory and
- Hypotheses are not theory.

Instead Sutton & Staw, (1995 pg. 378) agree with the position of Kaplan, (1964) and Merton, (1967) who posit that theory is the answer to the questions of *why*, that *theory is about the connections among phenomena, a story about why acts, events, structure and thoughts occur.* Despite Kaplan and Mertin's attempts, there is still a lack of consensus on what theory should constitute. There is still a disparity of what passes for strong theory in information systems research (I. Benbasat & Zmud, 2003; Desanctis, 2003; R. D. Galliers, 2003). Due to the multiple paradigmatic perspectives from which IS research can be based a range of theory types have emerged in IS research. Recognising this, Gregor, (2006) employs an ontological

perspective in order to present an understanding of the structural nature of theory in information systems, with her taxonomy of theory types in IS research being used to structure this section. This taxonomy was developed by establishing the primary goals of theory i.e.

> ***Analysis and description:*** *The theory provides a description of the phenomena of interest, analysis of relationships among those constructs, the degree of generalizability in constructs and relationships and the boundaries within which relationships and observations hold.*
>
> ***Explanation:*** *The theory provides an explanation of how, why and when things happened, relying on varying views of causality and methods for argumentation. This explanation will usually be intended to promote greater understanding or insights by others into the phenomena of interest.*
>
> ***Prediction****: The theory states what will happen in the future if certain pre-conditions hold. The degree of certainty in the prediction is expected to be only approximate or probabilistic in IS.*
>
> ***Prescription****: A special case of prediction exists where the theory provides a description of the method or structure or both for the construction of an artefact (akin to a "recipe"). The provision of the recipe implies that the recipe, if acted upon, will cause an artefact of a certain type to come into being.* (Gregor, 2006, pg. 619)

The taxonomy then goes on to describe five types of theory that have been employed in IS research.

Theory Type	Description
1. *Analysis*	• Says *"What is"*. • Most basic type of theory. • Descriptive Theory. • Necessary when nothing else is known about phenomena. (Fawcett & Downs, 1986).
2. *Explanation*	• Says *"How and why"*. • No testable propositions. • Theory for understanding.
3. *Prediction*	• Says *"What will be"*. • Testable predicted relationship.
4. *Explanation and Prediction*	• Says *"What is, how, why, when and what will be"*. • "Scientific Type" theory. • Testable propositions. • Recommendations for practice can be given.
5. *Design and Action*	• Says *"How to do"*. • Principle of form and function. • Methods and justificatory theoretical knowledge that are used in the development of IS. • "Design Science". • Contributions include: models, methods, foundational constructs, evaluations methods, metrics. • Testable propositions – design theory will assist other designers with similar requirements.

Table 3.6. Description of theory types in IS research. (Gregor, 2006)

The purpose of this research is to formalise a set of design principles, which when instantiated, have a positive impact on nurse's ability to process information displayed on an electronically generated AWTTS chart. As such, the primary focus of this research is to develop a theory of design and action. This implies that the research will formalise how a theory of design can be built. Furthermore, this type of theory is consistent with what can be created employing a critical realist (CR)

philosophical perspective. CR seeks to create theories of explanation, Table 3.6 defines this type of theory as a theory of 'how and why', with a theory of design and action being defined as a theory of 'how to do'. Where a 'theory of explanation' seeks to understand the mechanisms that lead to an event, a 'theory of design and action' seeks to understand the mechanisms that lead to an event and based on this understanding create explicit prescriptions for how to design a system to trigger a desired event (Gregor, 2006).

The following sections will present approaches for building design theory and will formalise the research design for this study. Further to this, rather than the principle contribution of this research being a *full-blown theory*, this research will develop an 'approximate' theory. Having established that this research will develop a theory of design and action, the following sections will describe pertinent research approaches that can be employed to develop such theories.

3.3.1. Design Science as an Approach for Developing a Theory of Design and Action

As established in section 3.3 this research will develop a theory of design and action. The purpose of this section is to present approaches that have been previously employed by academics when conducting Design Science Research (DSR). It will be demonstrated that some of these approaches have differing research entry points, differing definitions of the research phases and some of the phraseology employed by the respective academics have differed. This section will also present the DSR approach on which the research approach for this study will be based. The approach employed by this research needs to be scientifically rigorous and be able to transparently demonstrate how the contributions of this research were achieved. For these reasons, the research design needs to be able to demonstrate how it has adequately met the DSR Research guidelines as per Hevner et al., (2004).

Prior to identifying an approach for developing a theory of design and action it is useful to identify a framework for evaluating the utility of a particular approach. A number of academics in the IS field have presented guidelines for DSR efforts, including: Gregor & Jones, (2007), J. R. Venable (2006) and Carlsson, et al. (2011). However, this research will employ Hevner et al.'s (2004) *Guidelines for Design Science in Information Systems Research* in order to identify a suitable design science approach for this research (See appendix 3 for Author Centric Analysis of Design Science Approaches). Hevner et al. state that *the fundamental principle of design-science research from which our seven guidelines are derived is that knowledge and understanding of a design problem and its solution are acquired in the building and application of an artefact* (A. R. Hevner et al., 2004, pg. 82). This is consistent with the position of this research and these seven principles of design-science research are considered to be a seminal contribution to the legitimacy of DSR as a research approach.

While there appears to be a clear utility regarding Hevner et al.'s guidelines, Venable, (2010) observes that after their introduction, there is still remaining concerns regarding the *practicality and appropriate application* of the guidelines. In order to understand the impact of these guidelines on the IS academic community Venable conducted research to establish researcher's perception of the utility of the guidelines. Venable observed that the IS research community held doubts as to the legitimacy of the guidelines as a 'mandatory' checklist for evaluating Design Science Research (DSR) submissions for publication. There is an understanding that immature research projects may not yet have developed mature DSR artefacts, however these projects should not necessarily be seen as invalid. Furthermore, extensions and proposed changes to the guidelines were also proposed. What became clear from Venable's research is that the guidelines are *not the be all and end all to the development of DSR*. Despite these observations, these guidelines resonate with the requirements of DSR to be transparent, and they can provide useful recommendations for understanding the appropriateness of proposed procedural DSR approaches. The seven guidelines presented in Table 3.7 are employed in this chapter to demonstrate the legitimacy of the research approach employed for this study.

Guideline	Description
Guideline 1: Design as an artefact	Design-science research must produce a viable artefact in the form of a construct, a model, a method or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
Guideline 6: Design as a Search Process	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Table 3.7. DSR guidelines. Source (A. R. Hevner et al., 2004, pg. 83)

Having established that the DSR Research Guidelines will be utilised to demonstrate the legitimacy of the research approach for this study, this section will now present a background of DSR approaches and the DSR approach on which this study's research approach will be designed. This will begin by presenting Vaishnavi & Kuechler-Jr.'s DSR approach. This is a suitable research approach to present as it gives an insight into some of the underlying logic of DSR. Vaishnavi & Kuechler-Jr. state that their DSR approach is a logical extension of the reasoning process from the

general design science research framework. This research framework implies that the development of a design theory is procedural, where the research begins with awareness of a problem or a proposal, a design is suggested and an artefact is then built based on this design. Knowledge can then be learned from the development of the artefact and from evaluation of the artefact. Knowledge developed during these phases can then give insight into the design of the artefact itself (artefact mutability), limitations of the current study and directions for future research.

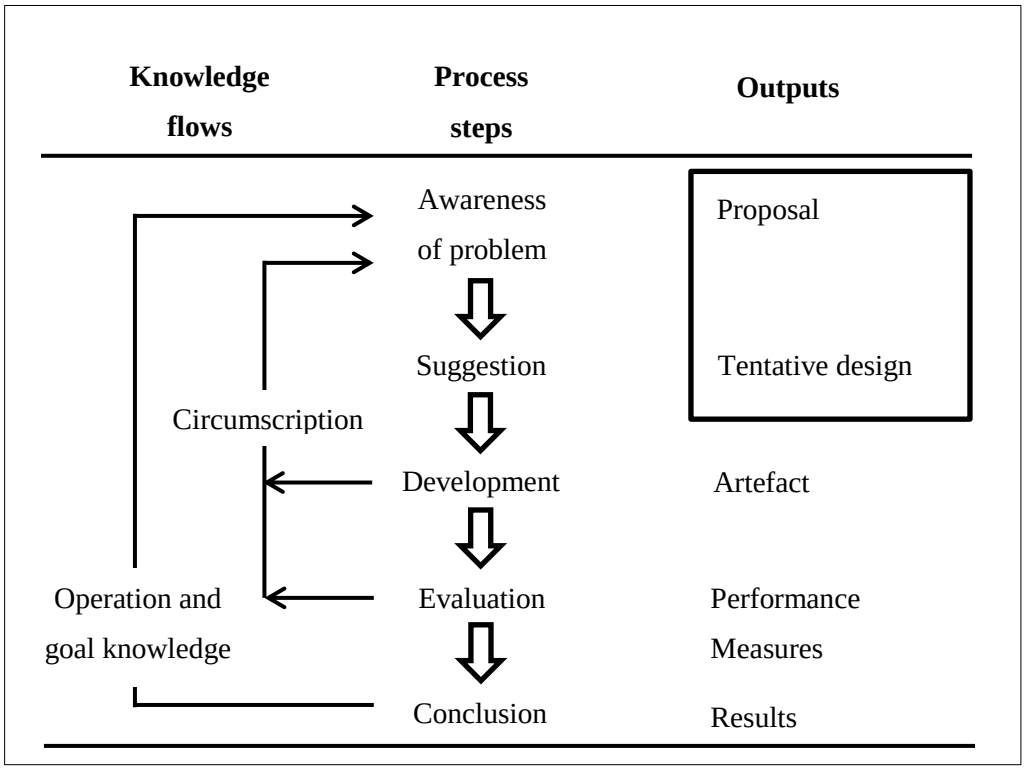


Figure 3.2. DSR framework. Source: (Vaishnavi & Kuechler-Jr., 2008, pg. 7)

Reflecting this observation, March & Smith, (1995) describe the activities of Design Science Research (DSR) as: *building, evaluating, theorising and justifying*, with the outputs of DSR considered to be either: *constructs, models, methods or instantiations.* The process of building, evaluating, theorising and justifying with regard to constructs, models, methods or instantiations can also produce theory as per Gregor & Hevner, (2013). Further procedural DSR approaches have been presented by: Baskerville, & Pries-Heje, (2010); Carlsson & Sawy, (2008); Gregor & Jones, (2007); Hevner, March, Park, & Ram, (2004); Nunamaker-Jr, Chen, & Purdin, (1990); Peffers, Tuunanen, & Rothenberger, (2008); Vaishnavi & Kuechler-

Jr., (2008); and Walls, Widmeyer, & El Sawy, (1992). While these approaches differ in some of the terminology and definitions employed these approaches all employ a procedural approach which follows a general *Design*, *Build*, *Evaluate* approach.

While this general procedural approach can be observed in DSR approaches, Peffers et al., (2008) observed that there was a lack of consensus in the DSR community with regard to creating a mental model for DSR. Furthermore, Peffers et al. observed that there was a lack of clear and transparent procedure in the DSR approaches previously presented. With this in mind, Peffers et al. designed the Design Science Research Methodology Process (DSRM). The purpose of this methodology was to create a standardised template on which DSR could be conducted. This approach is presented in Figure 3.3.

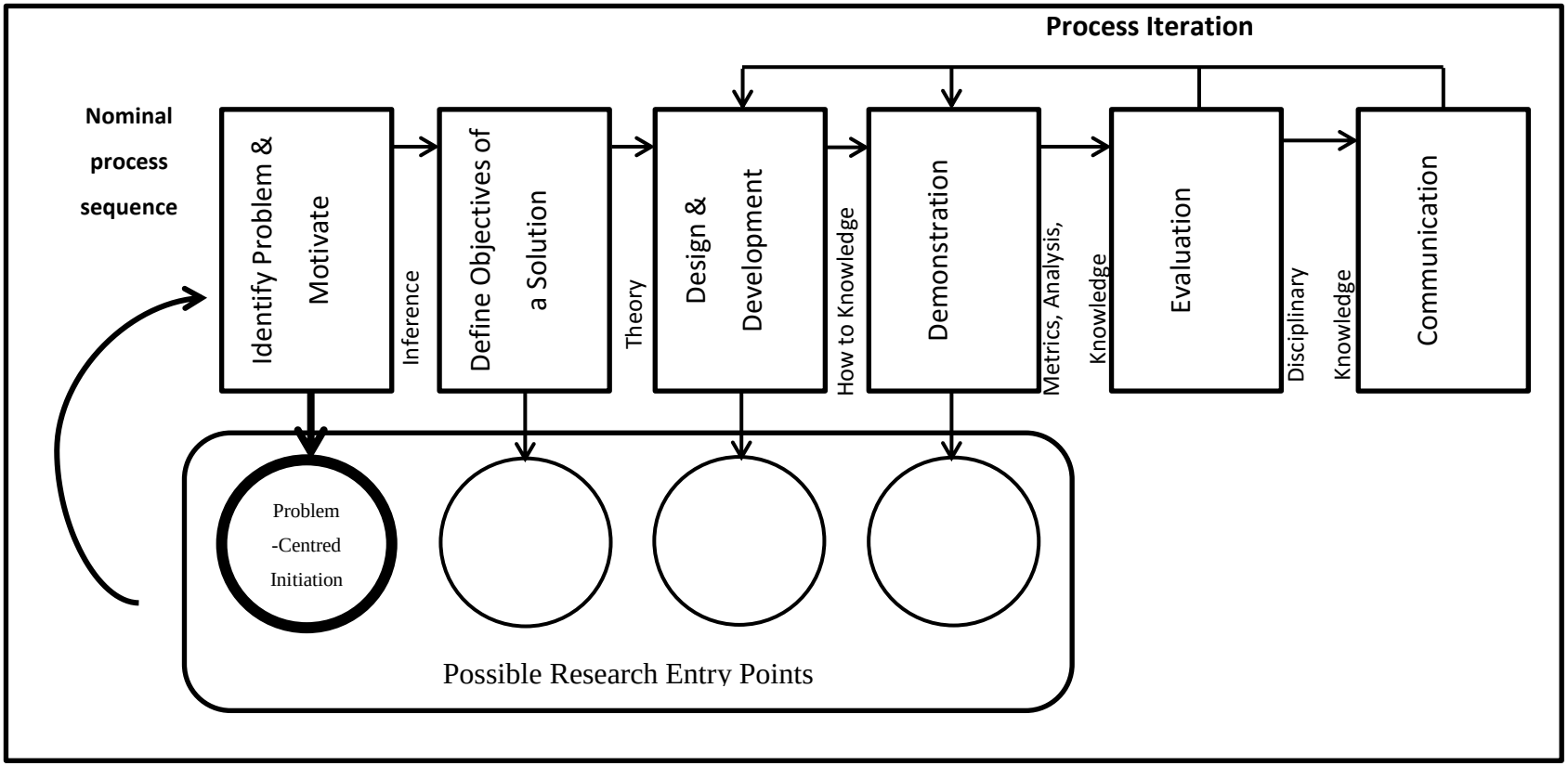


Figure 3.3. DSRM Process. (Adapted from Peffers et al., 2008, pg. 54)

While this approach is to be applauded in its efforts to create a transparent and comprehensive DSR approach there are elements of the approach that seem to be unclear. For example, the model begins with the phases of *Problem Identification and Motivation* and *Define Objectives of a Solution*. These phases are appropriate and are consistent with other models where *a clear definition of the research problem provides a focus for the research throughout the development process* (Nunamaker-Jr et al., 1990, pg. 635). However, the *Design & Development* phase appears to be ambiguous in terms of how the design & development is conducted. Peffers et al. describe this phase as the *create the artefact phase*:

> *Create the artefact. Such artefacts are potentially constructs, models, methods or instantiations (each defined broadly). This activity includes determining the artefacts desired functionality and its architecture and then creating the actual artefact* (Peffers et al., 2008, pg. 55).

Peffers et al. describe the design and development phase similarly to Vaishnavi & Kuechler-Jr., (2008) who posit the initial artefact design is based on a tentative design and an artefact is then developed based on human creativity. Vaishnavi & Keuchler-Jr. observe that this is a creative process and there are analogies to this phase in other research approaches, however, they also noted that this phase has been criticised for introducing non-repeatability to the process. The *design & development* phase as described by Peffers et al. does not appear to be consistent with Hevner et al.'s guidelines for DSR. In particular this approach does not meet Research Guideline 5 of Hevner et al.'s guidelines for DSR research. Guideline 5 states:

> *Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact* (A. R. Hevner et al., 2004, pg. 83).

It has been observed that the principle of dialogical reasoning requires the researcher to confront their preconceptions or prejudices which guided the research design. This principle requires the researcher to communicate the fundamental philosophical foundations that underpin the research and in the process require the researcher to be as transparent as possible with the audience. This procedural transparency is

considered to be an important component in ensuring a rigorous approach to scientific research has been taken (Lupia, 2008). Peffers et al.'s description of the design and development phase implies that a design is simply created whereas in reality this creative effort has been based on some theoretical foundation. This is consistent with Reymen, (2001) who observed that reflecting on a design process requires *contemplation of the designer's perception of the design situation and of the remembered design activities* (Reymen, 2001, pg. 32), (i.e. a designer has some design knowledge on which they designed the artefact). By simplifying this phase as a creative process it implies that dialogical reasoning is not performed and the rigor of the process is diluted. Furthermore, in order to adequately address Guideline 6 of Hevner et al.'s guidelines for good DSR, there is a necessity to present the design knowledge which dictates the design of the artefact. Guideline 6 states:

> *The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment* (A. R. Hevner et al., 2004, pg. 83).

The research presented in this thesis employs the position that DSR must adequately present the design theory which dictates the design of the artefact. While this improves the transparency and, therefore, the repeatability of the research effort it also provides an opportunity for the research to gain new insights into the problem environment. Walls et al., (1992, pg. 43) describes this knowledge as *kernel theories from natural or social science which govern design requirements,* with Carlsson et al., (2011, pg. 119) describing this as justificatory knowledge, i.e. *the underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design.* By presenting this design knowledge and the search process which was employed to synthesise the knowledge to the user, it demonstrates further rigor and can provide new insights into the problem domain.

3.3.2. Identifying a DSR Approach for Increased Rigor

Recognising the need for a coherent, transparent and adequately comprehensive DSR approach, Gleasure et al. (2012), developed the Process Model for Procedurally Transparent (PMPT) design science research (Figure 3.4).

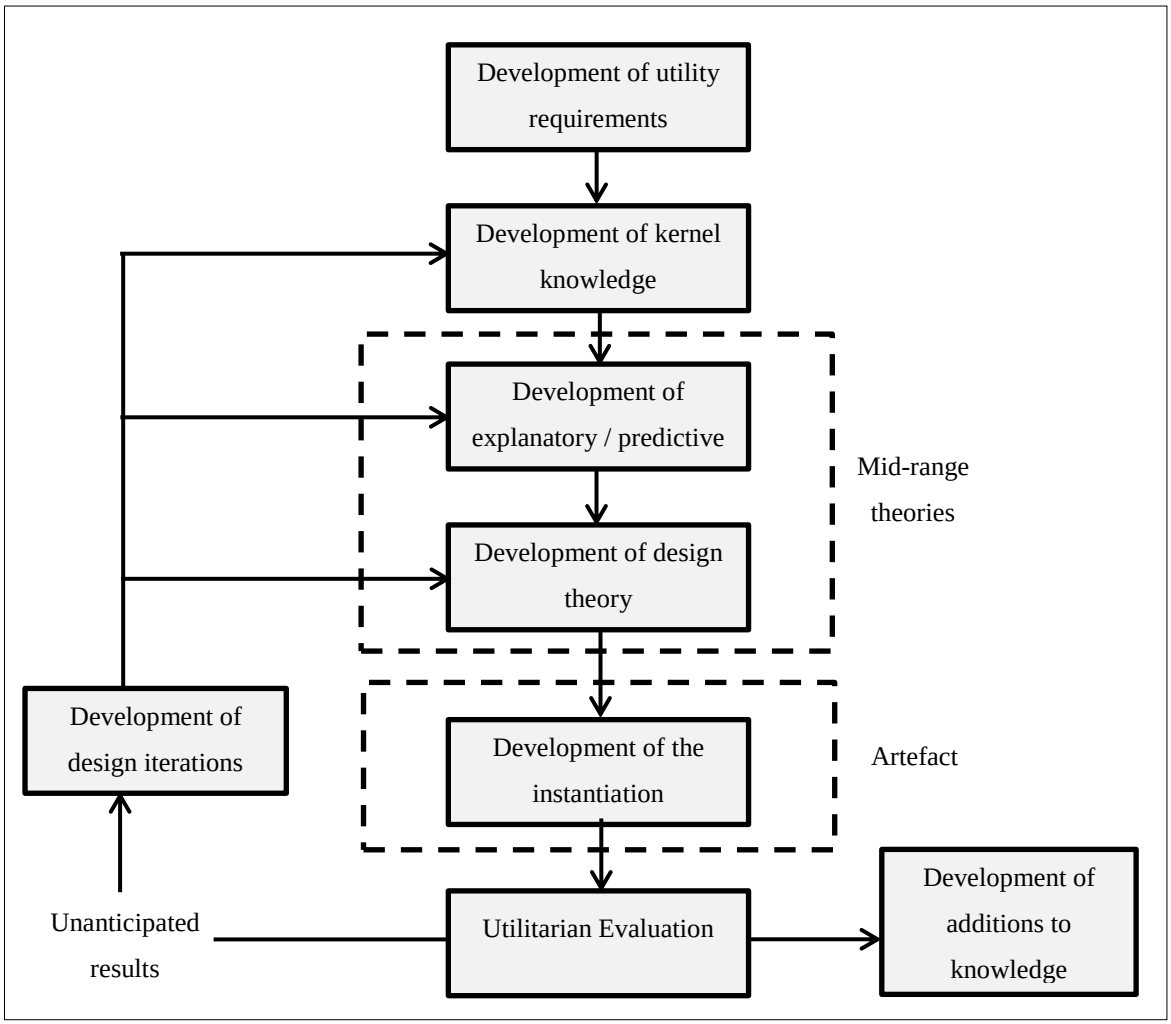


Figure 3.4. A Process Model for Procedurally Transparent DSR. Source (Adapted from Gleasure et al., 2012, pg. 4)

This model was designed by considering other existing DSR approaches and it establishes phases that aim to be procedurally transparent and rigorous. The following sections give a brief description of each of these phases.

3.3.2.1. Development of Utility Requirements

The first phase of the PMPT approach necessitates the development of the utility requirements. Simon (1996), describes designers as individuals who devise courses of actions with the aim of changing an existing, non-desirable situation into a preferred one with the difference between the existing and the desired situation being defined by the utility function (i.e. what is the expected value of the utility function of the design). This can also refer to the purpose and scope of the proposed design

artefact or "what the system is for" (Gregor & Jones, 2007). Hevner et al., (2004) posits that *the object of design science research is to develop technology-based solutions to important and relevant business problems* (A. R. Hevner et al., 2004, pg. 83).

By establishing this clear definition of what a system is for it provides a focus for the research project (Nunamaker-Jr et al., 1990). It is necessary to establish the general requirements for an artefact as there is a circular relationships between the general requirements for an artefact and the components of the artefact (Baskerville & Pries-Heje, 2010), that is to say that any designed artefact needs to *satisfy specified constraints* (Simon, 1988). Generalised requirements are set as the design theory to be developed is for a class of artefact rather than an individual artefact. For this reason utility requirements should be defined as meta-requirements (Walls et al., 1992) (i.e. requirements for a class of problem).

3.3.2.2. Development of Kernel Knowledge

While identifying the utility requirements for the design allows for the identification of the purpose and scope of the artefact to be designed, it does not provide a sufficient insight into the problem system to allow for development of potential design prescriptions. For this it is necessary to explore the *underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design* (Carlsson et al., 2011, pg. 119). This is consistent with Simon (1996), who observed that designing solutions to real world problems is not as simple as assembling a solution from components, but the designer must search for the appropriate components.

Gleasure et al. (2012), observe the necessity to adequately search for underlying theory from the natural or social or design sciences, stating that any design prescriptions created based on unsuitable theory are less likely to achieve the required utility. Furthermore, Goldkuhl (2004, pg. 67), observed that without grounding a design theory in its own background knowledge it is not possible to *formally connect the focused practical knowledge with its internal warrants*. Some disagreement exists in the literature regarding the necessity of this phase, as

observed in section 3.3.1. However, in order to adequately represent the search process for Design Science Research and in order to achieve procedural transparency there is a necessity to present the kernel knowledge that underpins a research project and the search process used to synthesise the information.

3.3.2.3. Explanatory/Predictive Model

Baskerville & Pries-Heje, (2010, pg. 274) posit that there are *two key elements in an explanatory design theory, the requirements and the components and their embodied relationship that explains the situation.* The presentation of the key elements and their relationships can be achieved through presenting an explanatory or predictive model. This model is a representation of the knowledge synthesised during the development of the utility requirements and the kernel knowledge.

The explanatory/predictive model consists of constructs which represent entities of interest in the theory (Gregor & Jones, 2007), with Hevner et al. (2004, pg. 78), observing that *constructs provide the language in which problems and solutions are defined and communicated.* Again, communication is an important component of design science research, with explanatory or predictive models providing a simple high level representation of the design process.

3.3.2.4. Development of the Design Theory

The design theory embodies knowledge of a practical nature (Goldkuhl, 2004), with Gregor & Jones, (2007, pg. 313) observing that *the distinguishable attributes of theories for design and action is that they focus on 'how to do something'. They give explicit prescriptions on how to design something*. As design can either be a noun or a verb, it is natural that there are two perspectives by which to view a design theory. From the perspective of a noun, a design theory may be a specific artefact, be it a blueprint or a drawing. Hevner et al. (2004), describe this as *design as an artefact*, with Carlsson et al. (2011, pg. 119), describing this as; *principles of form and function, the abstract "blueprint" or architecture that describes an IS artefact, either product or method/intervention.*

The corollary of this is that design as a verb can be described as; *principles of implementation. A description of processes for implementation the theory (either product or method) in specific contexts* (Carlsson et al., 2011, pg. 119). The design theory itself can be referenced to in a number of ways including; 'design principles' (Markus, Majchrzak, & Gasser, 2002), 'design framework' (Abbasi & Chen, 2008), 'design principles' (Kuechler & Vaishnavi, 2008) or 'design and development' (Peffers et al., 2008). A design theory should formalise prescriptive rules which can be practically applied to a class of artefact which when instantiated affect the required change in the problem system.

3.3.2.5. Development of the Instantiation

Following on from the development of the design theory, the next phase of the PMPT approach is to develop the instantiation. This step logically flows from the development of the design theory where practical knowledge has been established which can be instantiated. This phase describes the process of translating the design theory into an actualised design instantiation. Implementation is used to demonstrate the feasibility of the design (Nunamaker-Jr et al., 1990). Gregor & Jones, (2007) observe that the development of an expository instantiation is a practical demonstration of *principles of implementation.* March & Smith, (1995, pg. 260) observe that:

> *In much of computer science literature it is realised that constructs, models and methods that work "on paper" will not necessarily work in real world contexts. Consequently, instantiations provide the real proof.*

As such, the development of the instantiation phase demonstrates how the design theory can be practically implemented in a real world context. The development of the instantiation phase should demonstrate how each of the design principles can be practically instantiated and the form of the instantiation may take the form of a prototypes, (Gero, 1990) paper-prototypes, (Snyder, 2003) or fully operational systems. Furthermore, having developed the instantiation, it can be used to demonstrate the utility of the design theory (Gregor & Jones, 2007).

3.3.2.6. Utilitarian Evaluation

Having established in section 3.3.2.1 that the purpose of an artefact is to be useful in terms of affecting a required change in a problem system, the purpose of the utilitarian evaluation is to demonstrate the utility of said artefact. Hevner et al., (2004) observed that an appropriate evaluation of an artefact can demonstrate its utility, quality and efficacy, furthermore stating that the evaluation of an artefact is crucial. Hevner et al. posited that evaluation of an artefact is a fundamental component of DSR, as without evaluation, it is not possible to genuinely develop iterative improvements of the artefact.

Evaluation has been described as the *process of determining the worth, merit or significance* of artefacts (Scriven, 1998, pg. 85). Evaluation employs *systematic* data collection methods to establish how well a given artefact affects a required change on a problem system. This process is also known as establishing the utility of the artefact, where the goal is to develop a design theory which achieves the required level of utility in the problem system (Cleven, Gubler, & Hüner, 2009). Establishing this utility in DSR can be achieved through *artificial* or *naturalistic* approaches (Pries-Heje, Baskerville, & Venable, 2008). As such, a broad range of evaluation methods are appropriate for DSR, examples of artificial evaluation include experiments and simulations. However, evaluating the artefact in its natural setting using methods such as case-studies, interviews and surveys is considered to be *the real proof of the pudding* (J. Venable, 2006, pg. 186).

3.3.2.7. Design Process Evaluation/ Development of Design Iterations

As observed in the previous section, the evaluation of an artefact is an important component in iteratively improving the design of said artefact. This iterative improvement of an artefact or a design theory is a common component of procedural DSR approaches. This refinement of the artefact design is consistent with Simon, (1996) who observes that the design of an artefact needs to be flexible enough to facilitate feedback loops where improvements in the design can be integrated. Gregor & Jones, (2007, pg. 322) describe this phase as artefact mutability or *the*

changes in state of the artefact anticipated in the theory, that is, what degree of artefact change is encompassed in the theory.

The PMPT approach posits that the development of design iterations emerge from unexpected results that materialise from the utilitarian evaluation. These unexpected results affect the kernel knowledge, the development of explanatory/predictive model and the development of the design theory. While this position is logical, the explorative nature of design means that these unexpected results are likely to emerge at any stage of a procedural DSR approach. As noted in Guideline 6 for design science research, design is a search process. This implies that any phase of a design science approach can present unexpected results. However, while it can be argued that the exact design of the PMPT approach could be subject to change, the principle of formalising unexpected design knowledge after the utilitarian evaluation phase is fundamentally consistent with the notion of design mutability.

3.3.2.8. Development of Additions to Knowledge

As observed when discussing the design process evaluation phase of the PMPT approach, unexpected knowledge can emerge from any phase of the design process. Once this knowledge is formalised it can impact the earlier phases of the PMPT model. Hevner et al., (2004, pg. 81) posit that DSR addresses what are considered to be a 'wicked problem', that is to say problems that are characterised by:

- *unstable requirements and constraints based upon ill-defined environmental contexts,*
- *complex interactions among subcomponents of the problem and its solution,*
- *inherent flexibility to change design processes as well as design artefacts,*
- *a critical dependence upon human cognitive abilities to produce effective solutions and*
- *a critical dependence upon human social abilities to produce effective solutions.*

As these characteristics essentially describe problems where it is difficult to formalise knowledge about the context and imply that solutions are likely to be novel, any design theory that emerges from the process are likely to be unique.

Furthermore, as the design theories are design to approach a class of artefact, the findings are likely to be of interest to a broader community. Therefore, at the conclusion of a DSR effort the emergent conclusions should be formalised and communicated with this broader community. This phase is consistent with Guideline 7 for DSR, which states that DSR should be communicated effectively to the relevant industrial and scientific communities.

3.3.3. Formalising a Design Science Research Approach for This Study

Section 3.3.2 presented a detailed description of the Procedurally Transparent Process Model (PMPT) for Design Science Research (DSR), this particular approach is somewhat at odds with the scope of this research project. In the case of this research project two situated artefacts exist for which little design documentation exists, as such, it is necessary to perform an ex-post evaluation of the situated artefacts in order come to an understanding of the artefacts using familiar language. Gleasure et al., (2012) observe that in the case of ex-post evaluation, both their model and the DSRM process model develop by Peffers et al., (2008) serve two distinct functions, stating:

> *For example, an ex post evaluation of existing research with a model such as Peffers et al.'s may be used to break the research down into familiar sections, ensuring studies are compared according to the same components. An ex post evaluation of existing research with PMPT breaks down the research into familiar sections and identifies what aspects of the design process, if any, the authors have failed to document explicitly.*

In the case of this research, it is more suitable to adopt a focus that is consistent with that of the DSRM approach. However, criticism regarding the ambiguity of aspects of the DSRM approach is presented in section 3.3.1. Considering the focus of the PMPT for DSR is to increase the rigor of procedural DSR, it may be useful to reconcile aspects of the DSRM approach with definitions of the DSR phases as presented in the PMPT model. The following section presents an adapted version of

the DSRM process model that addresses the criticisms of the approach as presented in section 3.3.1.

3.3.3.1. The DSRM Process Model Updated for Increased Perceived Rigor

The purpose of this section is to reconcile the phases of the Gleasure et al.'s PMPT for DSR and Peffers et al.'s DSRM process. The section will begin by addressing the criticism of the DSRM process approach as presented in section 3.3.1 and will then consider each phase of the DSRM process approach to identify any adjustments that may need to be made to the phases of the model in light of the criticisms made.

Section 3.3.1 presented a detailed description of the design phases of the PMPT for DSR, the purpose of presenting this model in increased detail, is first to present this research's understanding of each of these phases, but also to abstract knowledge that identifies why each of these phases may contribute increased rigor. The criticism made of the DSRM process model was that it lacked perceived rigor at the *design and development* phase, with this phase considered to be ambiguous in terms of its reliance on human creativity. It was posited in section 3.3.1that this phase does not adequately address the principles of dialogical reasoning:

> *It has been observed that the principle of dialogical reasoning requires the researcher to confront their preconceptions or prejudices which guided the research design. This principle requires the researcher to communicate the fundamental philosophical foundations that underpin the research and in the process require the researcher to be as transparent as possible with the audience.*

The PMPT approach addresses these criticisms by introducing the Development of the Kernel Knowledge design phase. It was observed in section 3.3.2.2 that there is a necessity to explore the *underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design* (Carlsson et al., 2011, pg. 119). With this observation being consistent with Simon (1996), who observed that designing solutions to real world problems is not as simple as

assembling a solution from components, but the designer must search for the appropriate components. By introducing this element to Peffers et al.'s DSRM process model this should address criticisms of ambiguity in the design process.

A further attempt to remove ambiguity from the DSRM approach is to expand the *identify problem and motivation* phase to also include *development of the utility requirements*. Peffers et al. recognise that there is some disagreement in literature regarding the definition of this phase and argue that identification of the problem system does *not necessarily translate directly into objectives for the artefact because the process of design is one of partial and incremental solutions. Consequently, after the problem is identified, there remains the step of determining the performance objectives for a solution* (Peffers et al., 2008, pg. 55).

Peffers et al. recognise that the tasks of identifying the problem system and required changes in the problem system are discrete tasks, however, the decision to separate them appears to be a one of preference rather than any mandatory logical constraint. In the case of the PMPT for DSR, both of these phases are encapsulated in the *development of the utility requirements phase*. Gregor & Jones, (2007) when discussing the components of a design theory state that the first component to be described is the *purpose and scope* of the artefact. The purpose and scope of the artefact should refer to a general statement of the problem being addressed, stating *what the system is for*, this statement should include the required goals (or objectives) of the theory, including the boundaries of the theory. While the DSRM process appears to have made a preferential choice to separate *identify problem and motivate phase* and the *identify objectives for a solution*, this research will employ the *development of the utility requirements phase* as per Gleasure et al. (2012) and Gregor & Jones (2007).

The *design and development* phase of the DSRM process model requires the artefact to be created. The artefacts may include *constructs, models, methods or instantiations*. The description of this phase is broadly consistent with that of *Development of the Design Theory* phase as presented in section 3.3.2.4.

The phases of *Development of the Instantiation* and *Demonstration* also appear to have a similar function. The *development of the instantiation phase* appears to have a

technological focus, where the design rules that have been formalised in the *development of the design theory* phase are translated into technological rules that allow for a practical instantiation of the design artefact to be implemented. Peffers et al. described the *Demonstration* phase to be an opportunity for the artefact to demonstrate how the artefact can be utilised to solve a problem. While both of these descriptions have a different focus it is reasonable to posit that the practical instantiation of a design artefact is also a form of demonstration. Implementation of a design artefact can be used to demonstrate the feasibility of the design (Nunamaker-Jr et al., 1990). Gregor & Jones, (2007) observe that the development of an expository instantiation is a practical demonstration of *principles of implementation.* March & Smith (1995, pg. 260) observe that:

> *In much of computer science literature it is realised that constructs, models and methods that work "on paper" will not necessarily work in real world contexts. Consequently, instantiations provide the real proof.*

As such, the definition of the demonstration phase employed in this research will be closer to the ideals of the *development of the instantiation phase* as per Gleasure et al.'s PMPT for DSR.

The DSRM phases of *Evaluation* and *Communication* are broadly consistent with the PMPT phases of *Utilitarian Evaluation* and *Development of Additions to Knowledge*, as such, there is no need to make changes to these phases. The observations made in this section have been presented in order to establish a coherent DSRM process model that is consistent with the increased perceived rigor of the PMPT for DSR, without diverging from the goal of the DSRM approach. The updated phases of the DSRM approach and a brief description of each phase are presented in Table 3.8.

Design Phase	Description of Design Phase
1. Develop the utility requirements	Identify the purpose and scope of the class of artefact being evaluated. Identify the problem system and the required changes in the problem system. (Carlsson et al., 2011).
2. Develop the Kernel Knowledge	Formalising Kernel Knowledge allows for a deeper understanding of the problem system. Identify the theories which will govern the design process (Walls et al., 1992). Constructs identified in kernel knowledge, are to be manipulated by the system features. Establishing feasible objectives for the design solution based on knowledge developed.
3. Design and development	Create the design artefact. Artefact may be a construct, model, method or instantiation.
4. Demonstration	Demonstrate how the design theory formalised in the previous phase can be practically instantiated. Present the process for translating the design principles into design features.
5. Evaluation	Informed by kernel knowledge and problem and motivation. Establish the design principles that have been instantiated within the artefact to be evaluated. Evaluation will establish whether these design principals affect the required change in the problem system.
6. Communication	*Communicate the problem and its importance, the artefact, its utility and novelty, the rigor of its design and its effectiveness to researchers and other relevant audiences such as practicing professionals, when appropriate* (Peffers et al., 2008, pg. 56).

Table 3.8. The updated DSRM process model for increased rigor

3.3.3.2. Evaluation of the Updated DSRM Process Model

Having presented a number of recommendations for increasing the perceived rigor of Peffers et al.'s DSRM process model in section 3.3.3.1, the purpose of this section is to present an evaluation of the artefact through the lens of Hevner et al.'s, (2004) 8 guidelines for good Design Science Research (DSR). A key objective of this chapter is to present an approach on which the design of this research can be based and to justify the selection of the approach. While seminal DSR approaches are discussed, any DSR approach utilised needs to be cohesive, comprehensive and rigorous. The use of Design Science approaches in IS research has been prevalent in some form or another since the inception of IS research (Gregor, 2006), with many leading IS academics presenting formalised DSR approaches. These approaches have differentiated in their approach for research entry points, their requirements for knowledge development and research rigor. In an effort to consolidate the knowledge that has emerged from developing these approaches, academics have attempted to present cohesive and comprehensive DSR approaches that have been based on previous work. Peffers et al. (2008) and Gleasure et al. (2012) both present these kind of approaches. Peffers et al.'s DSRM process model was considered to be a useful approach due to its comprehensive nature, however, some issues of rigor arose with regard to some perceived ambiguity with regard to the design phases as described in section 3.3.1. Gleasure et al.'s PMPT approach was also identified as being cohesive, comprehensive and rigorous and while the definition of some aspects of the model were criticised, this model's focus on increased rigor is desirable. In order to address issues regarding the perceived rigor of the DSRM process model, section 3.3.3.1 presented an updated version of the DSRM process model that incorporated elements of the PMPT for DSR.

Section 3.3.1 established that this chapter would utilise Hevner's Guidelines for Design Science Research as a means of evaluating the suitability of the design science approach on which the research approach would be based. Table 3.9 presents a brief analysis of the updated DSRM process model in respect to the Guidelines for IS research as presented by Hevner et al. (2004).

Guideline for DSR Research	PMPT Approach	Guideline Satisfied?
Guideline 1: Design as an artefact	Artefacts can take the form of constructs, models, methods or instantiations (Peffers et al., 2008). Updated DSRM process model emphasises the development of constructs, models and artefacts during the development of explanatory/predictive model, development of the design theory and the development of the instantiation phases.	**Yes**
Guideline 2: Problem Relevance	Problem relevance or "what a system is for", can be described as a set of meta-requirements or goals that specifies the type of artefact to which theory applies and the scope of the problem (Gregor & Jones, 2007). This guideline is addressed during development of utility requirements.	**Yes**
Guideline 3: Design Evaluation	Simon (1988) describes the evaluation of design with respect to its utility as an important topic in the theory of design. The Updated DSRM process model addresses this during the evaluation phase.	**Yes**
Guideline 4: Research Contributions	Design science research can have different contribution types and these include well-developed theory, nascent design theory as operational principles or a situated artefact (Gregor & Hevner, 2013). The Updated DSRM process model addresses these contributions during the *design and development* and the *demonstration* phases.	**Yes**

Guideline for DSR Research	PMPT Approach	Guideline Satisfied?
Guideline 5: Research Rigor	Procedural transparency is one factor that determines the perceived rigor of a scientific research endeavour (H. K. Klein & Myers, 1999). Through presentation of the kernel knowledge that dictates the design of the artefact, the criticism of a lack of procedural transparency associated with the DSRM process model is addressed.	**Yes**
Guideline 6: Design as a Search Process	The search for theory to explain phenomena performed during the development of kernel knowledge, the search for design solutions to create the expository instantiation and the scientific evaluation of the expository instantiation constitute a search process to establish a design theory can affect a problem environment.	**Yes**
Guideline 7: Communication of Research	The development of additions to knowledge requires the formalisation of the emergent knowledge developed during the DSR project. This formalisation is written and communicated in a manner which satisfies guideline 7.	**Yes**

Table 3.9. Evaluation of the updated DSRM Process Model in terms of the 7 Guidelines for Design Science Research.

3.4. Design Science as Improvement Science

Having established that the updated DSRM process model approach is suitable for this study there are two further aspects that are unique to this research effort which must be addressed prior to presenting the final research approach. Design science can be characterised as *improvement research* (Vaishnavi & Kuechler-Jr., 2008). This is a useful description of DSR to consider, as the purpose of this research is to

essentially develop a set of design principles which, when instantiated, provides improved support for the decision making processes associated with the information processing task performed during clinical reasoning. The improved performance is to be measured in comparison to the Irish HSE's National Early Warning Score (NEWS) vital sign chart and the electronic National Early Warning Score (eNEWS) chart developed by the Health Information Systems Research Centre in University College Cork as part of a project funded by the Science Foundation Ireland (SFI).

If the design theory is to improve on the utility of the NEWS and eNEWS charts then there is a necessity to establish a baseline understanding of the artefacts by which the instantiated framework will be compared against. Good scientific research requires repeatability and transparency. In order to establish a baseline understanding of the usefulness of the existing situated artefacts, there is a necessity to establish a procedural transparent approach for synthesising design knowledge embedded in legacy situated artefacts. The second aspect of the research design that needs to be presented is the evaluation method. The evaluation method will allow for a comparative evaluation of each of the vital sign charts. As such, the following sections will present an approach for systematically discovering and synthesising design knowledge embedded in situated artefacts and the comparative evaluation method to be used in this research.

3.4.1. Discovering and Synthesising Design Knowledge in Situated Artefacts

Part of designing an approach for the adequate synthesis of design knowledge for a situated artefact is identifying the design stages knowledge needs to be gathered for. An updated version of Peffers et al.'s DSRM process model approach was developed in section 3.3.3.1, the DSRM approach was identified as a suitable model due to its comprehensive coverage of the stages of the design science process and was updated to increase the procedural transparency of the design phases.

The updated DSRM process model presents phases for; the synthesis of design knowledge necessary to create a theory of design and action, the development of an instantiation, the evaluation of the artefact, artefact mutability and development of

additions to knowledge. While these phases are appropriate for a start-to-finish DSR effort, it is not necessary to employ all of these phases when synthesising knowledge about situated artefacts. Peffers et al. suggest that there are multiple possible research entry points for the original DSRM model, with the logical implication of this observation meaning that a DSR project can begin with an artefact that has already been developed. In the case of the research project presented in this thesis, two situated vital sign charts exist, the paper-based National Early Warning Score (NEWS) Chart developed by the Irish Health Service Executive (HSE) and the electronically-generated NEWS (eNEWS) chart developed by the Health Information Systems Research Centre (HISRC) in University College Cork (UCC). As previously observed a situated artefact that was designed to resolve a problem has design knowledge or a design theory embedded within the artefact. In the case of both the NEWS and eNEWS charts, there is little documentation or literature that explains the design of the artefacts. As such, no formal design knowledge exists about each artefact. In order to formalise design knowledge embedded in these artefacts and to allow for improving the design of the artefacts, there is a need to present methods for discovering the design knowledge embedded in these artefacts and to present a research approach that allows for refinement of the existing design. The following sections will present appropriate methods for synthesising the design knowledge embedded in the NEWS and eNEWS charts, as well as a research design that will allow for iteration on the design of the charts.

3.4.1.1. Step 1: Identify the Utility Requirements for the Problem System

The utility requirements refers to the *purpose and scope* of the artefact being evaluated (Carlsson et al., 2011). The artefact being evaluated was developed in order to affect a required change in a problem system (Gleasure et al., 2012). As such, it is necessary to understand the problem system and the changes the artefact is expected to have on the system. In order to establish these utility requirements exploratory qualitative data collection can be performed. A literature review is an appropriate method for establishing the utility requirements for the artefact being investigated. This review can include practice or academic literature pertaining to the

artefact being investigated. If the utility requirements cannot be abstracted from literature then it may be necessary to perform interviews or focus groups with individuals involved with the design of the artefact. The result of this step should be a statement or statements describing the problem system and the required change the artefact is intended to have on the system.

3.4.1.2. Step 2: Identify the Kernel Knowledge for the Problem System

Kernel knowledge as utilised by Gleasure, (2012) is used as a more detailed description of the problem system identified in step 1. Walls (1992, pg. 43), describes kernel theory as *theories from the natural or social sciences governing the design process itself*. Any knowledge synthesized from the identification of kernel knowledge will in turn inform the utility requirements. Having identified the utility requirements for the system, it is then necessary to identify the extant knowledge and the theories that can explain the problem system. As such, it is necessary to search for literature regarding the problem system and study the reference material to establish the extant knowledge, data and theories that may explain the problem system. If the artefact has been designed employing a design science approach then the kernel knowledge explaining the problem system may already be documented. However, if the available literature regarding the design of the system does not include the kernel knowledge pertaining to the problem system then there is a necessity to explore and synthesize the kernel knowledge. A literature review is an appropriate method for establishing an adequate coverage of kernel knowledge relating to the problem system. Furthermore, synthesis of this literature can then provide insights into the fundamental theories that explain the problem system.

3.4.1.3. Step 3: Establish Meta-Design Principles

Design-principals relate to *principles governing the development or selection of system features* (Markus et al., 2002). Typically, unless an artefact has been designed using a design science approach the design principles for the artefact will not be documented. However, design principles are intrinsic to any artefact that is designed to make required changes in a problem system. In order to establish the design principles instantiated within the artefact being evaluated it is useful to identify all

possible design principles that are instantiated within the class of artefact being evaluated. In order to identify the design requirements a literature review is appropriate for adequately covering the literature and this also supports synthesis of the knowledge. By establishing these design principles for a class of artefact, a rigorous analysis of the artefact being evaluated is then possible, ensuring that all design-principles instantiated in the artefact being investigated are identified.

3.4.1.4. Step 4: Analyse the Demonstration

The artefact represents a manifestation or a demonstration of the instantiated design theory. The previous steps required inductive data gathering methods to discover design knowledge that can explain the design of a specific artefact. This step required empirical reflection of the instantiation itself. By identifying specific design features instantiated in the artefact, it is possible to confirm the presence of plausible design principles identified in step 3. If it is not possible to review the artefact being investigated then interviews with individuals or groups involved with the design of the artefact can be used to confirm the explanatory model.

3.4.1.5. Step 5: Formalise a Tentative Design Theory

The steps thus far presented have leveraged inductive data gathering and observational empirical information to identify a plausible design theory that explains the design of an artefact. Without having access to a precise account of a deductive design process for the formalisation of a design theory and an instantiation of the design theory, any design theory that emerges from this process must be viewed as a tentative design theory. That is to say that it is a design theory that is open to critique or change and is at most a best guess. However, in light of the mantra of DSR as improvement science, further iterations of this process can allow for further refinement of the design theory.

3.5. Evaluation Methods for Design Science Research

The approach presented in section 3.4 can act as an appropriate method for the discovery and synthesis of design knowledge embedded within the NEWS and eNEWS vital sign charts. The approach presents suitable methods for eliciting the

embedded design knowledge for DSR phases that is consistent with the updated DSRM process model. Having established the method that will be employed in this research for discovering and synthesising the design knowledge embedded in the eNEWS chart, the next aspect of the research design that needs to be presented is the comparative evaluation approach that will be employed to establish the comparative utility of the charts presented in this thesis.

The purpose of this section is to present evaluation approaches that are appropriate for evaluating artefacts in design science research. This is necessary to form a deeper understanding of evaluation in design science, but also it is necessary to provide an adequate coverage of evaluation approaches so an appropriate evaluation method can be identified for this research. As previously observed, evaluation is a *process of determining the worth, merit or significance* of an artefacts (Scriven, 1998). This process is also known as establishing the utility of the artefact, where the goal is to develop a design theory which achieves the required level of utility in the problem system (Cleven et al., 2009).

Establishing this utility in design science in a systematic way can be achieved through *artificial* or *naturalistic* approaches, assuming either an *ex post* (post artefact construction) or *ex ante* (pre artefact construction) perspective (Pries-Heje et al., 2008). As such, a broad range of evaluation methods are appropriate for DSR, examples of artificial evaluation include experiments and simulations. Hevner et al. (2004) identified suitable evaluation methods which include observational, analytical, experimental, testing and descriptive methods (*see Table 3.10*). This section will outline some of the appropriate methods which can be used in this study.

Evaluation Type	Description
Observational	Case Study: Study artefact in depth in business environment.
	Field Study: Monitor use of artefact in multiple projects.
Analytical	Static Analysis: Examine structure of artefact for static qualities (e.g. complexity).
	Architecture Analysis: Study for of artefact into technical IS architecture.
	Optimisation: Demonstrate inherent optimal properties of artefact or provide optimality bounds on artefact behaviour.
	Dynamic Analysis: Study artefact in use for dynamic qualities (e.g. performance).
Experimental	Controlled Experiment: Study artefact in controlled environment for qualities (e.g. usability).
	Simulation – Execute artefact with artificial data.
Testing	Functional (Black Box) Testing: Execute artefact interfaces to discover failures and identify defects.
	Structural (White Box) Testing: Perform coverage testing of some metric (e.g., execution paths) in the artefact implementation.
Descriptive	Informed Argument: Use information from the knowledge base (e.g., relevant research) to build a convincing argument for the artefact's utility.
	Scenarios: Construct detailed scenarios around the artefact to demonstrate its utility.

Table 3.10. Design evaluation methods. Source (Hevner et al., 2004, pg. 86)

3.5.1. Case Studies for Naturalistic Evaluation

Case study research is a common research strategy in social science allowing researchers to develop knowledge of individuals, social, political and organisational phenomena (Gilgun, 1994; Robert K. Yin, 2002). Gilgun commented that this rigorous investigation of a single unit allows for examination of multiple variables, how the unit of analysis is integrated within its context and allows for multiple perspectives to be taken into account. Gilgun also observed that this method of

research has been observed as being legitimate for research in practice as it allows the practitioner to apply their knowledge of similar applied situations to help them understand the current phenomena of interest. Benbasat, Goldstein, & Mead, (1987, pg. 371) identified the key characteristics for case study research as:

- *Phenomena is examined in a natural setting.*
- *Data are collected by multiple means.*
- *One of few entities (person, group or organisation) is examined.*
- *The complexity of the unit is examined/studied intensively.*
- *Case studies are more suitable for the exploration, classification and hypotheses development stages of the knowledge building process; the investigator should have a receptive attitude towards exploration.*
- *No experimental controls or manipulation are involved.*
- *The investigator may not set the specify the set of independent and dependant variables in advance.*
- *The results derive heavily on the integrative powers of the investigator.*
- *Changes in site selection and data collection methods could take place as the investigator develops new hypotheses.*
- *Case study is useful in the study of "why" or "how" questions because these deal with operational links to be traced over time rather than frequency or incidence.*
- *The focus is on contemporary events.*

As an evaluation tool for DSR case studies allow the researcher to observe the artefact in its natural environment and use their applicable knowledge to assess the success or failure of the artefact. This is in keeping with Hevner et al.'s (2004) observation that business needs and applicable knowledge are necessary for the development and evaluation of the artefact. As the case study method allows for the researcher to study the artefact within its natural environment and there is only one unit of analysis, the researcher can thoroughly evaluate the artefact and can observe the important variables pertinent to the success of the artefact. Venable, (2006) categorised case studies as *Naturalistic Evaluation* methods with other naturalistic methods including filed studies, surveys, ethnography or action research. While the

benefits of the case study have been noted in this section, it is necessary to consider the costs associated with this evaluation method. Venable noted that the evaluation might be difficult to perform as the phenomena must be examined in a complex real world environment where the researcher may not observe variables, which are fundamental to the study. Secondly, any observations may lack generalisability if the artefact is being observed in a specific environment.

While it can be argued that the case study approach can to a certain extent, overcome the issue with naturalistic evaluation methods not observing all relevant variables, the field study evaluation method can add to the generalisability of findings. In an effort to respond to the criticism that case studies do not provide a scientifically sound method for data collection, Lee (1989), proposed a series of recommendations (Table 3.11). Hevner (2004), distinguished field studies from case studies, by defining field studies as using multiple cases, while others consider a case study to be a form of field study (H. K. Klein & Myers, 1999), for the purpose of this research project Hevner's definition will be used.

Issues with Case Study Research	**Recommendations**
How to make controlled observations	Use of natural controls, *i.e.* *The control – focus one 1 person.* *The treatment – Move the person to a new environment.*
How to make controlled deductions	Logical verbal propositions (Qualitative Analysis).
How to allow for replicability	Independent investigator can try to replicate case study. Alternatively, the independent investigator can apply the same theory to different circumstances.
How to allow for generalisability	Field studies – i.e. more than one case study.

Table 3.11. Response to problems involved in a case study. Adapted from (Lee, 1989)

While Lee moved towards addressing some of the issues inherent in case and field study research, Venable argued that many of the issues with any naturalistic evaluation method has costs either in terms of scientific issues or with the cost of resources (time, money, personnel) it would take to complete the research. Considering some of the costs associated with naturalistic evaluation methods, it is worthwhile considering some *artificial evaluation* methods which are suitable to DSR. Venable noted the alternative to naturalistic evaluation us artificial evaluation, where artificial or non-realistic methods are developed to evaluate the artefact (Pries-Heje et al., 2008; Venable, 2006a). Pries-Heje noted that artificial evaluation methods included experiments, simulation and mathematical proofs.

3.5.2. Artificial Evaluation Methods

The degree to which scientific endeavours can classify whether an artefact has reached its desired goals (i.e. success), can be classified by the degree to which the artefact has satisfied success variables (Curtis, 1980; Torgerson, 1958). Torgerson noted that in order to achieve this, there is a necessity to identify observable constructs and measures that correspond with the artefact satisfying success variables. Artificial evaluation methods allow for the measurement of these success variables through providing the researcher with the ability to measure *cause-effect relationships*, *conditional statements* and *control flow* (i.e. *the evaluation of structured coding)* (Curtis, 1980). Basili et al. (1986), noted that the framework for experimental evaluation consisted of four phases: *1) definition, 2) planning, 3) operation* and *4) interpretation* (Basili et al., 1986, pg 733) *and* acts as an extensive reference point for IS experimental evaluation (Table 3.12*).*

I. Definition					
Motivation	*Object*	*Purpose*	*Perspective*	*Domain*	*Scope*
Understand Assess Manage Engineer Learn Improve Validate Assure	Product Process Model Metric Theory	Characterise Evaluate Predict Motivate	Developer Modifier Maintainer Project Manager Corporate Manager Customer User Researcher	Programmer Program/Project	Single Project Multi-project Replicated Project Blocked subject-project

II. Planning		
Design	*Criteria*	*Measurement*
Experimental designs Incomplete block Completely randomised Randomised block Fractional factorial Multivariate analysis Correlation Factor analysis Regression Statistical models Non-parametric Sampling	Direct Reflections of cost/quality Cost Errors Changes Reliability Correctness Indirect reflections of cost/quality Data coupling Information visibility Programmer comprehension Execution coverage Size Complexity	Metric definition Goal-question-metric Factor-criteria-metric Metric validation Data collection Automatically Form design and test Objective vs. subjective Level of measurement Nominal/classificatory Ordinal/ranking Interval Ration

III. Operation		
Preparation	*Execution*	*Analysis*
Pilot Study	Data collection Data validation	Quantitative vs. qualitative Preliminary data analysis Plots and histograms Model assumptions Primary data analysis Model application
IV. Interpretation		
Interpretation context	*Extrapolation*	*Impact*
Statistical framework Study purpose Field of research	Sample representativeness	Visibility Replication Application

Table 3.12. Summary of the framework of experimentation. Source (Basili et al., 1986, pg 734)

Artificial evaluation methods are beneficial for the evaluation of IS artefacts as they provide a platform which is closer to the scientific ideals as per Bryman (*Reliability, Replication and Validity*). As rigorous controls in experiments enable the researcher to isolate the impact of experimentally manipulated factors and collection and analysis of data can help to identify cause-effect relationships (Curtis, 1980). Artefact mutability is also supported through artificial evaluation, as controlled experiments and the iterative learning process inherent to this method parallels the necessity for iterative knowledge building in the DSR process (Basili et al., 1986; A. Hevner & Chatterjee, 2010).

While the benefits of experimental evaluation have been noted, there are also shortcomings inherent to this method. Hailey and Basili, (1981) noted that the constants in one environment, which do not cause variations in work performance, may cause significant variations of behaviour in a different work environment and developed a meta-model for explanation of these variations. This is consistent with the lack of generalisability which can be attributed to artificial evaluation methods, if the controlled experiment is focused on a context specific (Curtis, 1980). Further to this, as there are many important variables which can contribute to system success, there is a possibility that some variables will not be accounted for. Take for example

a software development team working on a complex program. Logic would suggest that the more difficult a problem, the more team member will have to work on the project and the project will be completed in a shorter amount of time. However, in the case of software development, there are many variables to consider within this assumption. With added team members, duplicate code becomes more difficult to detect. Similarly, more complex problems can lead to less structured coding or individuals may be apprehensive about beginning to develop complex programs (Basili & Freburger, 1981; Basili & Selby, 1985).

3.5.3. Embracing Naturalistic and Artificial Evaluation Methods

Considering the benefits and costs associated with both naturalistic and artificial evaluation methods, it can be beneficial to include both evaluation methods in the Design Science development cycle. Venable (2006), proposed an activity framework for design science adapted from Nunamaker et al.'s multimethodological approach to IS research (1991). This activity framework proposes four research activities: *(1) theory building, (2) solution technology invention, (3) naturalistic evaluation and (4) artificial evaluation* (Venable, 2006, pg. 185). This framework suggests that each of the design science research activities are interdependent, therefore, artificial evaluation methods can contribute to naturalistic evaluation methods and the converse is also true. As such, DSR can benefit from employing both artificial and naturalistic evaluation methods. In light of the appropriate approaches for design science presented in this section the following section will present the evaluation methodology that is to be used for this study.

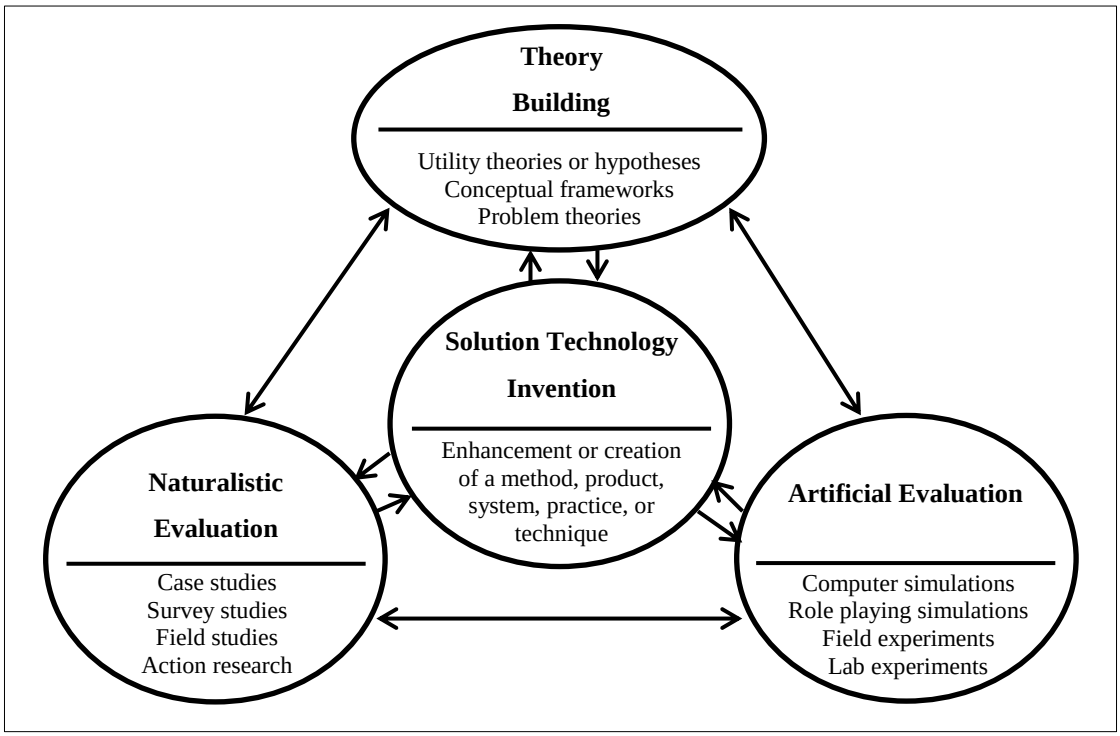


Figure 3.5. A framework and context for design research. Source(J. Venable, 2006, pg. 185)

3.6. Research Design

Section 3.5 and its dependant sections 3.5.1 and 3.5.2 will present the research design and evaluation approach for this research, as well as the considerations for choosing the particular research designs. The precise evaluation methods to be employed for this research will not be presented in this chapter; it will be presented in chapter 4. This is necessary as prior to establishing a suitable evaluating method, there is first a necessity to formalise design knowledge about said artefact. This section presents an overview of the evaluation approach. The evaluation approach demonstrates the general principles that inform the final evaluation method. Prior to presenting the evaluation approach there is first a necessity to present the research design. The research design presents the phases of this research and demonstrates at a high level what the purpose of each of these phases will be. It is a necessity to present the overall research approach prior to the evaluation approach as the evaluation method is directly impacted by the research approach. Figure 3.6 demonstrates the directional relationship amongst the research design, the evaluation approach and the precise evaluation method.

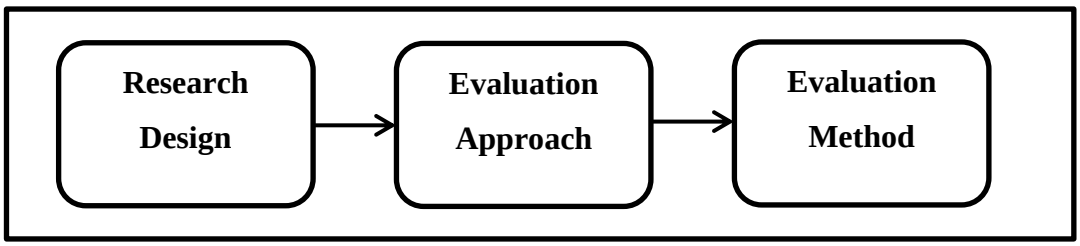


Figure 3.6. Directional relationship between research approach, evaluation approach and evaluation method.

3.6.1. A Research Design for Iterating on Situated Artefacts.

As observed in section 3.6 there is a necessity to establish the research design prior to presenting the evaluation approach. In the case of this research a site has been identified where a paper-based version of the Irish HSE's National Early Warning Score (NEWS) chart has been in use and the first version of the Health Information Systems Research Centre's (HISRC) electronic NEWS (eNEWS) system has been trialled. The eNEWS system has been identified as a suitable platform on which the framework for REVIEWS can be applied. This is possible as the developer that created the eNEWS system is interested in further development of the chart functionality already instantiated within the eNEWS system.

Two primary implications emerge from identifying a site that has used both the NEWS and eNEWS systems. The first implication concerns the design entry point for this research. As the charts have already been used by nurses working in the hospital these artefacts represent situated artefacts. Initial investigation of the design of these artefacts implies that a DSR approach has not been employed to create these artefacts, as such, the usual design knowledge (*utility requirements, kernel knowledge, design principles)* that is formalised prior to developing an artefact (the NEWS and eNEWS charts in this case) has not been completed. In order to conduct a rigorous and transparent DSR study there is a necessity to discover and synthesise the design knowledge embedded in these charts. It was noted in section 3.3.1, that there can be a number of entry points for a design science research (DSR) effort. This point was further expanded on in section 3.4.1, where it was observed that DSR can begin after the initial design iterations of an expository instantiation have been completed. This observation lead to the development of the inductive design

knowledge synthesis and formalisation presented in section 3.4.1, where the design knowledge embedded within an expository instantiation is retrospectively synthesised and this knowledge can then be used as the basis for designing the specific evaluation method. This approach will therefore be employed in this research design in order to discover and synthesise the design knowledge embedded in both the NEWS and the eNEWS charts.

The second implication of identifying a site where situated artefacts have been in use is that there is an opportunity to discover how useful the situated artefacts are in relation to their purpose. Furthermore, there is an opportunity to compare the utility of the situated artefacts to each other. This represents a significant opportunity that should be taken advantage of. While the paper-based and electronically generated charts serve the same general purpose, each chart has some different design features. A comparative evaluation of the charts represents an opportunity to formalise the utility of individual design features and to identify possible bias that nurses may have towards using a paper-based or an electronically generated vital sign chart. Considering this, there is a necessity to incorporate an evaluation of both the NEWS and eNEWS charts into the research design for this study.

Finally as the objective of this research concerns formalising a set of design principles for electronic vital sign charts (*The framework for REVIEWS)*, there is a necessity to employ a DSR approach that ensures that the design, implementation and evaluation of the artefact is presented in a logically structured and transparent way. Section 3.3.3.1 presented an updated version of Peffers et al.'s Design Science Research method (DSRM) process model that employs aspects of Gleasure et al.'s Process Model for Procedurally Transparent (PMPT) Design Science Research (DSR). This approach will be employed to structure the iterative design of the

framework for REIVEWS. The research will consist of three phases. This will allow for four iterations of the framework for REVIEWS. The phases are described in greater detail in Table 3.13.

	Problem Formalisation		***New Design Input***	
	Phase 1 Nov 2013	***Phase 2 Feb 2014***	***Phase 3 Dec 2014***	***End***
Purpose of Design Phase	***Reflect on design and usefulness of the paper-based NEWS chart.***	***Reflect on design and usefulness of the electronic eNEWS V1.0 chart.***	***Introduce deductive design theory development process to help create eNEWS V2.0.***	
Practical and Academic Design Knowledge	**What tasks does the chart support?** **What design features support each task?**	**What can the previous evaluation tell us?** **To what extent do design features support tasks?**	**What can the previous evaluation tell us?** **What theoretical knowledge can be leveraged to improve chart design?** **How can these theories be leveraged?**	**What can the previous evaluation tell us?** **What can the design process tell us?**
Resulting Design Artefact	***Tentative Design Theory*** ***REVIEWS Alpha***	***Tentative Design Theory*** ***REVIEWS Beta***	***REVIEWS V0.1*** ***Consists of 23 Design Principles***	***REVIEWS V1.0*** ***Consists of 24 Design principles***
Comparative Evaluation	**NEWS Vs. Legacy Charts**	**eNEWS V1.0 Vs. NEWS**	**eNEWS V2.0 Vs. eNEWS V1.0 Vs. NEWS**	

Table 3.13. Three phases of this research design and the design artefact that emerges from each phase.

3.6.2. Comparative Evaluation Methodology for this Research

Having presented a high level overview of the research design for this study, this section will present the evaluation approach for this research. The evaluation approach essentially refers to the general approach that will be employed for this research. As the specific evaluation method requires the discovery and synthesis of the design knowledge embedded in the NEWS and eNEWS chart, the specific evaluation method for the comparative evaluation of the NEWS and eNEWS charts will be presented in chapter 4.

While the precise evaluation method for this research cannot be presented in this chapter, it is possible to present the research approach. As demonstrated in Figure 3.6, the research design has a direct impact on the evaluation approach. In section 3.5, it was established that this research is using a site where two similar vital sign charts will be in use: the eNEWS chart and the NEWS chart. In order to demonstrate the relative usefulness of each chart there is a necessity to design a research approach that allows for comparative evaluation. A typical DSR approach requires a utilitarian evaluation of the artefact that emerges from the research. Scriven, (1998, pg. 85) describes evaluation as *the process for determining the worth, merit or significance of entities*. Typically artefacts are evaluated based on whether they adequately affect a required change on a problem system (Peffers et al., 2008). While this approach is suitable for evaluating the unique and new artefacts that are typically the result of DSR, in cases where the DSR seeks to iterate on situated artefacts there is a necessity to establish a comparative evaluation approach (Creedon et al., 2014). A comparative evaluation approach allows for the analysis of differences and similarities with comparison providing greater depth of comprehension, explanation and interpretation of a phenomena (Mayer, 1989; Przeworski, 1987; Ragin, 2014; Salminen, 1998). In an attempt to abstract the key components of evaluation and comparison research, Vartiainen, (2002) proposes 4 principles for comparative evaluation (Table 3.14) these principles will be used to present the evaluation approach that this research will follow.

Principle	Description
1. *Selection of the object for evaluation*	What constructs are being evaluated? What constructs are you using as a measurement for usefulness?
2. *The level of comparison*	What is the scope of the evaluation? How can you accomplish the evaluation?
3. *Conceptual comprehension*	How are you defining the constructs that are being measured? Necessary for communication.
4. *Analysis of the findings of an evaluation*	How are you identifying relationships and patterns amongst the data?

Table 3.14. Principles for comparative evaluation and description of principles. Source (Vartiainen, 2002).

3.6.2.1. Selection of the Object for Evaluation

Prior to evaluating an artefact there is first a necessity to establish the objects for evaluation. Weber, (2012) observes that a construct may be a thing, composite thing, a property, a class, an attribute, a state, a lawful state, an event, a lawful event, the history of a thing or the interaction between things. Design Science Research requires the demonstration of the usefulness of a design theory. This is typically achieved through the evaluation of an instantiated design theory in the form of an artefact (S. Weber, 2010). In order to establish how useful said artefact is, there is a necessity to formalise an understanding of the purpose and scope of the artefact as well as kernel knowledge that helps explain the problem system (Goldkuhl, 2004). Through formalising this knowledge it becomes possible to identify attributes of a useful system. *Response time*, e*ase of use*, *data timeliness*, etc. may be attributes that contribute to a useful information system. As such, the 'things' that will be comparatively evaluated will be the HSE's paper-based NEWS chart, the HISRC's electronically-generated eNEWS chart and the eNEWS chart with the instantiated framework for REVIEWS, as well as the attributes that demonstrate the usefulness of the charts to be identified from kernel knowledge pertaining to the design of the charts (Identified in chapter 4).

3.6.2.2. The Level of Comparison

While principle 1 requires the selection of the particular object for evaluation, the purpose of principle 2 is to establish the *unit of analysis*. In social science research, evaluations often employ qualitative approaches that focus either on the individual or the group as the level of analysis (Kaplan & Maxwell., 2005). In the case of physical science the molecule may be the unit of analysis (Hirscheim, 1985). Vartiainen suggests that the unit of comparison can include; socially constructed systems or subsystems of these with the level including internal or external comparison, or a comparative evaluation may identify the differences between particular objects.

As established in section 3.6.2.1, the 'things' that will be compared will be the respective vital sign charts, with the attributes of the vital sign charts being used to present the differences or similarities between the two objects. Considering the purpose of this section is to present how we can accomplish the evaluation, there is a necessity to reflect on this research's position with regard to what knowledge is and how valid knowledge can be attained. Section 3.2.4 establishes that this research will employ a Critical Realist (CR) epistemological approach, that is to say that reality exists independantly of individuals, however, the only way to know about that world is through human conjectures. This implies that human bias must be recognised when considering the level of comparison and furthermore, this implies that either qualitative, quantitative or mixed-method approaches can be employed to collect this data.

A researcher's perspective of reality and how knowledge about this reality can be formed has an impact on suitable methods that can be used, which in turn dictates what unit of analysis can be employed to facilitate understanding of the phenomena of interest. Considering the importance of capturing knowledge regarding human bias, this research will employ a method that can capture this type of data. Section 3.5.1 establishes that each phase of the research design needs to capture knowledge pertaining to the usefullness of charts and what particular design features contribute to the usefullness of charts. Any method of data collection needs to ensure that this knowledge can be adequately captured. Section 3.5.2 presents a number of methods that can be suitable for collecting data during evaluation of artefacts, these

approaches include natural and artificial methods. Reflecting the preferential status afforded to naturalistic evaluation (*the real proof of the pudding* (Venable, 2006a)), this study will employ a naturalistic approach. Section 3.5 discussed appropriate research methods for Design Science Research (DSR), with section 3.5.1 describing how case studies are useful for developing knowledge of individuals, social, political and organisational phenomena (Gilgun, 1994; Robert K. Yin, 2002). As such the case study method will be employed for this research.

Dyer Jr. & Wilkins, (1991) suggest that single cases are superior to multiple cases as the quality of theory that emerge from single case studies are often stronger than those that emerge from multiple cases. Eisenhardt, (1991) suggests that there is no clear evidence that single cases inherently generate better theories, however suggests that richer description of the case study can help to persuade the reader as to the validity and worthiness of the research, this is consistent with observations made by (Siggelkow, 2007). In order to give more insight into the context and to attempt to 'tell a better story', section 4.1.1 presents a description of the research site which served as the single case for this research.

A further consideration that impacts the selection of a site for case studies is the nature of DSR, in that it is iterative and there is an acceptance that knowledge search methods will not produce 'perfect' models of knowledge (J. G. March, 1988). This acknowledgement that DSR requires iterative design also impacts the decision regarding the number of sites that are needed to conduct the research. Single sites are considered to be useful when a case is critical, extreme or unique (R. K. Yin, 1994) and multiple sites are appropriate when cross-case analysis and comparison are needed (Darke, Shanks, & Broadbent, 1998). The choice of single or multiple cases depends on which approach is most appropriate for maturing design knowledge. Lee & Baskerville, (2003) observe that a multiple site case study allows for generalisability across cases, while a single case allows for generalisability within the case, therefore allowing for a deeper description of the individual case. This search for a deeper understanding of the context of the phenomenon is consistent with the mantra of design science research where a design-feedback loop is used to form a deeper understanding of the problem and ultimately produce better solutions

(Gregor & Hevner, 2013). As such it can be observed that a single-site case study can act as an appropriate ground for conducting DSR studies.

3.6.2.3. Conceptual Comprehension

Vartiainen observes that it is crucial that the concepts employed by research are clearly defined in order to ensure that the different parties associated with the reseach can all interpret the concepts in the same way. Effective communication of research has been noted as an important quality in design science research (A. R. Hevner et al., 2004; Peffers et al., 2006), where the importance of transparently communicating all aspects of the research process has been noted as a requirement for good DSR. This is of particular importance in cases where artefacts are to be comparatively evaluated, as differences in understanding of the concepts being presented can have an impact on the data gathered or how the data is analysed. Wengraf, (2001) discusses the structuring of interview questions and observes that questions are often theory-led. While it is normal for questions to be theory-led, this can lead to a lack of comprehension for parties who are not familiar with the theory.

As established in section 3.6.2.2, this research will employ interviews to collect data regarding the unit of analysis. In order to ensure that the concepts presented in the interviews are correctly understood by the interviewees and any other interprested parties, practical examples of the theory will be presented as part of each interview question (See appendix 4 for these examples).

3.6.2.4. Analysis of the Findings

As identified in section 3.6.2.2, this research will use interviews as the primary means for capturing data regarding how useful the respective charts are in terms of the attributes or qualities that will be identified in the kernel knowledge. Analysis of qualitative interview data is typically performed using an inductive process. Thomas, (2006, pg. 238) defines inductive analysis as *approaches that primarily use detailed readings of raw data to derive concepts, themes or a model through interpretations made from the raw data by an evaluator or researcher.* Creswell, (2007) presents an overview of inductive analysis approaches defined by Huberman & Miles., (1994); Madison, (2005); and Wolcott, (1994) (Table 3.15).

Analytic Strategy	(Madison, 2005)	(Huberman & Miles., 1994)	(Wolcott, 1994)
Sketching Ideas		Write margin notes in field notes.	Highlight certain information in description.
Taking Notes		Write reflective passages in notes.	
Summarising field notes		Draft a summary sheet on field notes.	
Working with words		Make metaphors.	
Identifying codes	Do abstract coding or concrete coding.	Write codes, memos.	
Reducing codes to themes	Identify salient themes or patterns.	Note patterns and themes.	Identify patterned regularities.
Counting frequencies of codes		Count frequency of codes.	
Relating categories		Factor, note relations variables, build a logical chain of evidence.	
Relating categories to analytic literature			Contextualise in framework from literature.
Creating a point of view	For scenes, audience, readers.		
Displaying the data	Create a graph or picture of the framework.	Make contrasts and comparisons.	Display findings in tables, charts, diagrams and figures; compare cases; compare with a standard.

Table 3.15. General data analysis strategies, by authors. Source: (Creswell, 2007, pg. 149)

Considering the evidence in literature that an inductive analysis approach is appropriate for analysing interview data, the evaluation approach for this study will employ inductive analysis. This research employs Thomas's, (2003) inductive approach for qualitative data analysis, presented in Table 3.16.

Phase	Description
1. Preparation of raw data files (Data cleaning)	Format the raw data files in a common format if required. Make a backup of each raw data file.
2. Close Reading of Text	Read raw text in detail to become familiar with the text and gain an understanding of emerging themes from the interviews.
3. Creation of Categories	Define categories or themes. Upper categories defined by research objectives, lower level categories defined by emerging themes.
4. Overlapping coding and uncoded text	Identify areas of text where multiple themes have emerged. Identify text where no themes have emerged.
5. Continuing revision and refinement of category system	Search for subtopics such as contradictory points of view and new insights. Select appropriate quotes that convey these emerging messages.

Table 3.16. A general inductive approach for qualitative data analysis. Adapted from (David R. Thomas, 2003)

3.7. Conclusion

The purpose of this chapter was to present the research design for this study as well as the evaluation approach that will dictate how vital sign charts will be evaluated. A research design typically presents a plan for achieving a research objective through identifying the means of understanding the phenomena, collecting data about the phenomena and analysing the data to formalise new knowledge about the phenomena. In the case of this research the objective was to employ a design science approach to iterate on the design of an electronically-generated vital sign chart.

Prior to presenting a means for collecting data about an artefact, there was first a necessity to present this research's paradigmatic perspective position. This was necessary as this research's perspective of reality has an impact on how valid

knowledge about that reality can be obtained. Section 3.2 presented the three principal philosophical strands that must be considered when conducting research (ontology, epistemology and methodology) and established that this research is to employ a post-positivist Critical Realist position, i.e. ontologically, a reality independent of external factors exits and from an epistemological perspective the data collected must reflect on the subjective nature of how data is collected about the phenomena. From a methodological perspective, this implies that quantitative, qualitative or mixed-method approaches are suitable methods for collecting valid data about a phenomena.

Having established the paradigmatic position of this research, section 3.3 presented a brief summary of the types of theory that are typically established in information systems research. This section went on to establish that a theory of design and action is an appropriate theory type to emerge from ISR, with section 3.3 going on to present research approaches for formalising theories of design and action. While procedurally driven design science research (DSR) approaches were presented from academics such as Hevner, Peffers, Carlsson and Vaishnavi, this research employed aspects of Gleasure et al.'s *Process Model for Procedurally Transparent* (PMPT) design science research to update Peffers et al.'s Design Science Research Method (DSRM) process model approach to ensure greater levels of procedural transparency. These approaches were reconciled as both approaches represent a comprehensive overview of DSR, with PMPT adding a focus on transparently communicating each phase of the research, while DSRM represents a common language by which DSR can be presented thus increasing the rigor of the research process and ensuring that the design approach can be replicated by interested parties.

A practical consideration for this research, that presented a novel problem that has received little attention in DSR literature, is the necessity to iterate on situated artefacts where a design science approach has not been used to create said situated artefacts. Typically DSR presents artefacts that have been developed using a *Design-Build-Evaluate* approach where innovative artefacts are developed to solve wicked problems (see section 3.3.2.8 for description of a wicked problem). However, in cases where there is a necessity to iterate on an artefact to solve a wicked problem,

there is first a necessity to formalise design knowledge about the situated artefact and evaluate said artefact based on the function it should perform or an *Evaluate-Build-Evaluate* approach. In order to address these issues a number of steps are presented in section 3.4.1 designed to formalise methods to discover and synthesise design knowledge embedded in the phenomena.

A key area in which DSR differs from typical social sciences is the goal of the data collection. While the goal of data collection and analysis in social science is typically either to analyse a phenomena, explain a phenomena, make predictions about a phenomena or to explain a phenomena, the goal of data collection and analysis of DSR is to explain and establish the usefulness or utility of an instantiated design theory. The utility of an artefact is measured based on its impact on a problem system. As this research is iterating on a situated artefact, a comparative evaluation method is established, where the utility of a given vital sign chart is evaluated based on its usefulness in relation to the previous iteration of the chart. This approach ensures that the iterative design process takes logical design choices and the approach also allows for feedback to be given on the success of individually instantiated design principles.

Having presented the key considerations that need to be incorporated in the research design for this study, section 3.6.1 presents the research design and the evaluation approach for this research. The research design consists of an initial two data gathering and evaluation phases. This research design consists of three phases for refinement of the framework for REVIEWS. The first phase will discover and formalise design knowledge embedded in the Irish HSE's paper-based NEWS chart and using this design knowledge will formulate an evaluation protocol to comparatively evaluate the utility of the NEWS chart compared to legacy charts used by nurses. The second phase will also discover and synthesis design knowledge embedded in the electronically-generated eNEWS chart. This design knowledge will contribute towards the understanding of electronic vital sign chart design and will allow further refinement of the framework. Phase 3 will act as this research's first phase where the design of the artefact is affected by the design knowledge formalised in this phase, which will be informed by the design knowledge

discovered during phase 1 and 2 of this research. This will allow for further iterative improvement of the framework for REVIEWS. The framework will be instantiated in V2.0 of the eNEWS chart with the final evaluation and analysis of the evaluation allowing for further reflection on the design theory which can allow for further refinement of the framework. This process is described in greater detail in Table 3.13

.

Having identified the key philosophical considerations for this research and presented the research design for this study, the following chapter will be used to implement the research design. Chapter 4 will present phase 1 and 2 of the research design where the design knowledge embedded in the NEWS and eNEWS charts synthesised and formalised and will represent the Alpha and Beta versions of the framework with a comparative evaluation of each chart also being presented.

Chapter 4 : A Reflective Analysis of Design Knowledge Embedded in the NEWS and eNEWS Charts

4.1. Introduction

This chapter will present the process for discovering and synthesising the design knowledge embedded in both the NEWS and eNEWS charts. In order to improve on the design of an artefact, there is a necessity to understand the artefact, to understand its scope and purpose and to understand the rationale for choosing and implementing specific design features. In the case of both the NEWS and eNEWS charts, there is a deficiency of literature or technical documentation that describes the design process for creating the two charts. As such, there is a necessity to reflect on the design of each of these charts and to theorise regarding the problem space the artefacts are designed to impact and to identify useful design features instantiated in the charts.

Building on the research design presented in chapter 3, this chapter presents two research phases. The first phase will theorise and abstract design knowledge regarding the design of the Irish HSE's paper-based NEWS chart. The knowledge elicited and formalised in this phase will provide the basis for evaluation of the NEWS chart, with the NEWS chart being comparatively evaluated to legacy charts nurses would have prior experience of using. The design knowledge that emerges from this process will be captured and formalised as the first iteration of the framework for REVIEWS (version Alpha).

The second phase presented in this chapter will discover and synthesise design knowledge embedded in the eNEWS chart. The eNEWS chart has been designed to mimic the functionality of the paper-based NEWS chart, however, due to the nature of electronic charts and the relatively early stages of development of the chart, there are a number of design differences between the NEWS and eNEWS charts. The evaluation criteria established in phase 1 will provide the basis for comparative evaluation of the NEWS and eNEWS charts. Having reflected on the comparative evaluation the framework will be further refined, incorporating the design

knowledge discovered during phase 2. Prior to presenting these research phases a description of the case-study site for this research is presented in section 4.1.1.

4.1.1. The Research Site for this Study

As discussed in section 3.6.2.2, giving a description of the research site from where a case study is conducted can help to 'tell a better story' regarding the research, and can give more context to the data collected. As stated in chapter 3, this research employs a Design Science Research (DSR) approach to achieve the objectives of this research, i.e.

> *To design, implement and evaluate a set of design principles, which when instantiated, have a positive impact on* nurses *ability to process information presented on an electronically generated AWTTS chart. The set of design principles will be referred to as the framework for REVIEWS.*

The design, implementation and evaluation of any artefact should be directly influenced by the context of the phenomena, that is to say, the design of the artefact is affected by the type of problem, the people who the artefact is designed for and the feedback that these people give regarding the success or failure of the artefact itself. The research presented in this thesis was conducted in Nenagh General Hospital, Nenagh, Co. Tipperary. Nenagh General Hospital is part of the University of Limerick (UL) Hospitals and serves the County of North Tipperary and the surrounding areas. Nenagh General is classed as a Model 2 UL hospital, in that it provides ambulatory care, diagnostics, selected medical in-patient, medical assessment and local injuries unit services. An advanced Nurse Practitioner Unit was also appointed in Nenagh Hospital in 2013.

During the evaluation phases of this research presented in sections 4.2, 4.3 and 6.3 respectively, 8 nurses with an average of over 21 years' experience, 12 nurses with an average of over 21 years' of experience and 9 nurses with an average of over 20 years' experience were interviewed. Throughout the second and third evaluation periods trials of the eNEWS system including hardware, software and network componentry were conducted in the Medical Assessment Unit. While the primary

objective of the evaluation periods was to assess the utility of the observation chart designs, the trials of the complete eNEWS systems also provided an opportunity for management, doctors and nurses to observe the system in place and give constructive criticism of the project. The nurses interviewed during the 3 trial periods were interviewed based in Ward 1, Ward 2 and the MAU ward were all selected for interview based on their availability.

4.2. Phase 1: Evaluating the Utility of the Irish HSE's Paper-Based Early Warning Score Chart: A Reflective Data Gathering Phase for the Design of the Framework for REVIEWS

In 2011 the Irish Health Service Executive (HSE) introduced the National Early Warning Score (NEWS) system and associated training program. The objective of this program is to improve patient outcomes through the identification of patients at risk of deterioration. The NEWS system is an example of an Aggregate-Weighted Track-And-Trigger System (AWTTS), where weighted scores are associated with individual vital signs recorded within specific parameters. The aggregated score is then linked to appropriate care protocols (Prytherch et al., 2010). A key component of this system is the observation chart. The chart enables health care professionals to record and present patient vital signs on a standardised paper-based interface. It is well documented as to how data can be used in an intelligent manner which facilitates the understanding of data (Baker et al., 2009). However, due to the nature of paper-based systems (Johnson, Jellinek, Klotz-Jr., Rao, & Card, 1993) and the reality of a health care practitioner's heavy workload, there is little time to process vital sign data, which enables them to identify trends in patient deterioration (Baldursdottir, Jonsson, Jonsdottir, Alma, & Möller, 2011). While the current paper based system in use by the HSE does not allow for this, an electronic version of the NEWS system has been developed which presents the same chart interface as the HSE's NEWS chart. This electronic version of NEWS could provide a platform to improve how data is presented to the user in a way that facilitates the understanding of the data.

Prior to developing this facility, there is the necessity to understand the purpose and scope of the Irish HSE's NEWS chart and establish how useful this chart is in the context of its purpose. Presented in this research phase is the knowledge which was synthesised in order to establish the purpose and scope of the NEWS chart, as well as the methods used for evaluating the usefulness of the NEWS chart and the results of this evaluation. Furthermore, this research phase presents the first iteration of a design framework for the visualisation of patient data in a manner that facilitates clinical decision making for nurses caring for patients at risk of deterioration. This will be known as the framework for the Retrospective Evaluation of Vital Sign Information from Early Warning Systems (REVIEWS). This iteration of the framework for REVIEWS (version Alpha) represents the first tentative design framework which is designed to meet the objective of this research. This tentative design framework will provide the basis for the design of the evaluation protocol to be used to comparatively evaluate all charts presented in this thesis.

The NEWS chart was designed by the HSE in order to aid identification of patients at risk of deterioration. This knowledge has been established in the training material for the NEWS system provided by the Irish HSE (Avard et al., 2011), as well as the report provided by the Royal College of Physicians regarding the development of the NEWS system. Beyond this, little documentation exists regarding the design, development and the usefulness of the NEWS chart. Without establishing this knowledge, it becomes difficult to design and develop an artefact that can legitimately improve on the support provided by the Irish HSE's NEWS chart. This knowledge regarding the purpose, scope, design and usefulness of an artefact such as the NEWS Chart can also be referred to as design knowledge (Gregor & Jones, 2007). Any artefact that has been designed and developed in order to affect a required change on a problem system has embedded design knowledge (Gregor, Müller, & Seidel, 2013). The following section describes the approach that was used to acquire and synthesise this knowledge in a transparent and coherent manner that can then allow for the evaluation of the NEWS chart.

4.2.1. Design of the NEWS Chart

As little documentation exists regarding the design, development and usefulness of the NEWS chart, there is a necessity to theorise about the NEWS chart as an instantiation of design knowledge. While Design Science Research (DSR) typically employs a *design-build-evaluate* approach where a novel artefact is designed to resolve a unique problem, it is also appropriate for DSR to have a later research entry point, where inductive and empirical approaches can be employed to formalise design knowledge about existing situated artefacts (Gregor & Hevner, 2013; A. R. Hevner et al., 2004; Peffers et al., 2008). As described in section 3.6.1, this research will employ an updated version of Peffers et al.'s, (2008) Design Science Research Methodology (DSRM) process model. This model is consistent with other design science approaches that follow a general *design-build-evaluate* approach. The DSRM process model is updated for this research in order to address some criticisms that were observed in chapter 3 regarding the perceived rigor of the DSRM approach.

Table 4.1 demonstrates the process for the approach for DSRM, a brief description of each of the design phases and how this research will formalise the design knowledge for each design phase.

Design Phase	Description of Design Phase	Inductive Methods
1. *Develop the utility requirements*	Identify the purpose and scope of the class of artefact being evaluated. Identify the problem system and the required changes in the problem system. (Carlsson et al., 2011)	Exploratory data gathering. Literature search.
2. *Develop the kernel knowledge*	Formalising Kernel Knowledge allows for a deeper understanding of the problem system. Identify the theories which will govern the design process. (Walls et al., 1992) Constructs identified in kernel knowledge, are to be manipulated by the system features. Establishing feasible objectives for the design solution based on knowledge developed.	Exploratory data gathering. Review of academic and industrial literature. Creative process of adapting kernel knowledge to identify likely objectives.
3. *Design and development*	Create the design artefact. Artefact may be a construct, model, method or instantiation. Propose a tentative design theory.	Creative process of reflecting on literature and analysing the artefact to abstract design principles.
4. *Demonstration*	Demonstrate how the design theory formalised in the previous phase can be practically instantiated. Present the process for translating the design principles into design features.	Present the process for instantiating the design theory.
5. *Evaluation*	Informed by kernel knowledge and problem and motivation. Establish the design principles that have been instantiated within the artefact to be evaluated. Evaluation will establish whether these design principals affect the required change in the problem system.	Semi-structured interview is conducted to evaluate artefact based on its intended utility.

Table 4.1. The updated DSRM approach.

Having established the process for the updated DSRM approach, the following sections describe how this process was employed to discover the design knowledge

embedded within the Irish HSE's NEWS Chart. The following sections describe the methods used to discover and synthesise the knowledge as well as the findings for each of the design phases.

4.2.1.1. Identify the Utility Requirements

As observed in the introduction to this research phase, the observation chart being evaluated is part of the Irish HSE's NEWS system. The NEWS chart itself provides the basis for presenting vital sign information to nurses and it has been found that the design of the charts has an impact on nurse's ability to make care decisions in an accurate and timely manner (Preece, Hill, Horswill, & Watson, 2012; G. B. Smith et al., 2008).

Having reviewed the existing documentation regarding the design of the NEWS system it was possible to establish that the purpose of the NEWS chart is to aid in the early identification of acute illness in patients. This in effect is the problem system the chart has been designed to have an impact on. The required changes in the problem system can be defined as: *to provide easier recognition of patient data and to aid identification of abnormal clinical parameters for patients*. It was possible to establish the utility requirements for the NEWS Chart by reviewing the training material provided by the HSE for the NEWS system (Avard et al., 2011) and the design document provided by the Royal College of Physicians (Royal College of Physicians, 2012).

Problem system	• *Early identification of acute illness in patients.*
Required changes in problem system	• *Provide easier recognition of patient data.* • *Aid identification of abnormal clinical parameters for patients.*

4.2.1.2. Identify the Kernel Knowledge

Kernel knowledge is concerned with identifying the theories from the natural and social sciences which govern the design process (Walls et al., 1992), with kernel

knowledge providing a deeper understanding of the problem system itself. The problem system the NEWS chart is designed for can be defined as; *identification of abnormal clinical parameters for patients*, this is defined in the utility requirements. Exploring the kernel knowledge pertaining to the problem system provides a deeper understanding of this statement. Two key components can be abstracted from the defined problem system. The first component is related to the data processing stage of clinical reasoning, where nurses process information and vital sign data in order to allow them to come to an initial understanding of a patient's health (Levett-Jones et al., 2010). The case defined by the problem system refers to identification of abnormal vital signs, this logically implies the role of the nurse is to identify both normal and abnormal vital signs and understand the difference between them. Having established this, there is a clear necessity to explore the information processing activities employed by nurses when performing clinical-reasoning.

The second component of the problem system refers to the problem system context, i.e. to aid identification of abnormal clinical parameters for patients. This is consistent with Carlsson et al. (2011), where it was observed that design knowledge is deeply embedded in the context of the problem system in which the artefact is placed. The training material for the NEWS system provided by the HSE places an emphasis on the nurse using their clinical reasoning to help them to identify patients at risk of deterioration (Avard et al., 2011). By including patients in the defined problem system, this implies that *abnormal vital signs* are abnormal for specific patients i.e. what might be abnormal for one patient may be normal for another.

Reflecting on the components of the problem system, it is important to identify the kernel knowledge that can give insight into the practices involved in processing patient vital sign data, which ultimately allows a nurse to come to an initial understanding of a patient's health. In order to establish an adequate coverage of clinical reasoning literature, a literature review is performed. Three leading scientific full-text databases were searched for relevant literature pertaining to nurse clinical reasoning: Science Direct, JSTOR and EBSCO Academic Search Complete were used to identify relevant literature. Google Scholar was also used to track key literature that may not have been available using the previously mentioned

databases. This literature search produced 83 results, with further analysis of these papers producing 33 papers relating to how nurses process information as part of clinical reasoning. A Concept Centric Matrix (CCM) was developed based on the 33 papers, where information-processing tasks were identified. This allowed for the identification of commonalities amongst the literature and helped to establish a coherent and adequately comprehensive coverage of the literature. This approach is consistent with the approach suggested by Webster et al. (2002).

From this literature, 4 dominant information processing tasks and 5 less common tasks were identified which nurses employ when processing information (See Appendix 2 for a publication centric analysis of information processing tasks performed during clinical reasoning). The 4 most dominant tasks were;

- Pattern recognition,
- Interpreting cues,
- Matching previous situations and
- Relating information.

4.2.1.3. Establish the Meta-Design Principles

The third step of the updated DSRM process model as described in section 3.3.3.1 is the design and development phase. This phase would typically require the creation of the new design artefact. However, when reflecting on an instantiation where little design literature exists there is a necessity to first formalise a pool of all potential design principles. This is consistent with an inductive approach as described in section 2.3.3. Section 3.4.1 describes a process whereby literature pertaining to a class of artefact can be analysed in order to establish potential design principles that could be instantiated in a class of artefact. This step is performed prior to analysing a specific instantiation as it allows the researcher to formalise an understanding of specific design features and will increase the likelihood of identifying design features instantiated in the specific artefact. Design principles for a class of artefact are referred to as meta-design principles as per Walls et al. (1992), i.e. a design theory does not address the design of a specific artefact, but a class of artefacts. In

this case the class of artefact being referred to are AWTTS Observation Charts. The previous section established at a high level that the purpose of the NEWS Chart is to facilitate users in processing vital sign information to enable them to come to an initial understanding of a patient's condition. As such, the emphasis when reviewing design literature regarding observation charts was to identify design features that facilitate the information-processing phase of clinical reasoning.

In order to adequately cover the extant literature regarding vital sign observation chart design, a literature review was performed. The same scientific literature databases used in the previous phase were used for this literature search. This search yielded 68 papers with a review of these papers identifying 12 relevant papers. While few studies empirically evaluated observation chart design features (Horswill, Preece, Hill, Christofidis, & Watson, 2010; Preece, Hill, Horswill, & Watson, 2012) to see its impact on nurse clinical reasoning skills, any paper that made reference to how design principles were instantiated in the observation chart being studied were also included. Furthermore, any literature that visually presented the observation chart was included as analysis of the chart could be performed to identify design principles instantiated in the chart (Cahill et al., 2011; Chatterjee et al., 2005; Jones, 2012; Mitchell et al., 2010; Preece, Horswill, et al., 2010; Preece et al., 2013). A Concept Centric Matrix was used to capture the design features that were instantiated in other observation charts and the following meta-design principles were identified as having an impact on information processing:

- Colour coding,
- Standardisation of chart design,
- Graph vital signs statistics,
- Separate all vital signs recorded,
- Preferential presentation of information perceived to be more important and
- Instructions to use chart included on same page as chart.

4.2.1.4. Analyse the Demonstration

As described in section 3.4.1.4, an artefact represents a manifestation or a demonstration of the instantiated design theory. The purpose of this phase is to consider the artefact from the perspective of the design knowledge previously formalised in the identification of the utility requirements, the kernel knowledge and the meta-design principles. This phase also allows for empirical knowledge to be introduced, i.e. what design features can be observed as being instantiated. Findings from reviewing the NEWS Chart are outlined in Table 4.2.

Design Principle	Benefits Identified in Literature
Standardised approach to chart design	This is consistent with studies that demonstrate that using AWTTS vital sign observation charts that are based on defined standards, results in improvement in quality of plotting charts as well detection of anomalies within the vital signs recorded. (Chatterjee et al., 2005)
Colour coding of vital statistics	Colour coding of vital signs has been identified as an effective way of drawing attention to abnormal observations in AWTTS systems. (Preece et al., 2013)
Graphing vital signs	By presenting data in a graphical manner it can lead to faster and more accurate decision making. (Baker et al., 2009)
Graphing vital signs separately	By graphing all vital signs separately it has been observed that separating all vital signs recorded can result is faster and more accurate identification of abnormal vital signs. (Christofidis, Hill, Horswill, & Watson, 2014; Preece et al., 2013)

Table 4.2. Instantiated design principals from the Irish HSE's NEWS Chart

Having used theoretical knowledge and empirical observations to establish that these design principles have been instantiated in the Irish HSE's paper-based NEWS chart, it now becomes possible to present an understanding of the design theory in the guise of a tentative design theory.

4.2.1.5. A Tentative Design Theory for the Framework for REVIEWS

The fifth step of the process for formalising design knowledge for situated artefacts as described in section 3.4.1.5 is to present a tentative design theory. This tentative design theory is subject to future amendments as further knowledge is discovered and formalised, however, the design theory as presented in this step represents the design knowledge as understood at this stage of the research project. The objective of this research is concerned with the formalisation of a framework of design principles for the design of electronic observation charts. This will be referred to the framework for *Retrospective Evaluation of Vital sign Information from Early Warning Systems* (REVIEWS). The knowledge discovered and presented thus far in section 4.2 provides the basis for the Alpha version of the framework for REVIEWS and is presented in Table 4.3.

Required Change in Problem Environment	**Design Principle**	**Description**
Support initial interpretation of vital sign information. Support discrimination between more and less important information. Support identifying relationships amongst data points. Support matching between analogous situations. Support predicting of outcomes.	*1*	Design principles that affect required changes.
	2	Standardised approach to chart design.
	3	Colour coding of vital signs.
	4	Graphing of vital signs.
	5	Graph each vital sign separately.

Table 4.3. The Framework for REVIEWS (Version Alpha)

Table 4.3 presents the information processing tasks that the framework is to be designed to affect, with the 5 design principles representing the current knowledge of design principles that can be instantiated to cause these desired changes. What is unclear, as of yet, is which of these design features are likely to impact specific information processing tasks. However, the design knowledge represented in the

Alpha version of the framework represents an adequate platform from which to design the evaluation of the artefact. As the evaluation is to employ a semi-structured interview method for data collection, it is also likely that further design principles will be discovered and the relationship between specific information processing tasks and design features can be discovered and formalised. Having established the design knowledge embedded within the NEWS chart, we can begin to develop an approach for establishing the utility of the chart. Utility refers to how well the instantiated design principles affect the required change in the problem system. The following section describes the considerations for developing a design method for this study and presents the results of the evaluation.

4.2.2. Evaluation

Having defined the problem system the NEWS chart was designed to affect, the instantiated design principles and the impact they are to have on the problem system, it is then possible to identify a method for evaluating the utility of the artefact. Chapter 3 presented a high level evaluation approach that will guide the evaluation method for this research. Furthermore, chapter 3 established that this research would utilise interviews in a naturalistic setting to establish the comparative utility of the respective vital sign charts. The purpose of this section is to present the particular evaluation method for this research, as well as the particular method for analysing the data gathered. Prior to presenting this, it is useful to first present a brief summary of the role of evaluation in design science research.

Evaluation has been described as a process of determining the worth, merit or significance of artefacts (Scriven, 1998), with evaluation using systematic data collection methods to establish how well a given artefact affects a required change on a problem system . This process is also known as establishing the utility of the artefact, where the goal is to develop a design theory which achieves the required level of utility in the problem system (Cleven et al., 2009). Establishing this utility in design science can be achieved through artificial or naturalistic approaches (Pries-Heje et al., 2008). As such, a broad range of evaluation methods are appropriate for design-science, examples of artificial evaluation include experiments and simulations. However, evaluating the artefact in its natural setting using methods

such as case-studies, interviews and surveys is considered to be the real proof of the pudding (Venable, 2006a). Reflecting the preferential status afforded to naturalistic evaluation, this study identified a setting in which the Irish HSE's chart has been in use as a site for data collection.

The problem system identified consists of two characteristics, the first of these relates to the information-processing component of clinical reasoning, with the second characteristic referring to the context of the decision being made. It has been noted that decision-making in a clinical environment is complex due to the nature of the work environment as well as the complexity of individual patient cases (Fairchild, 2010; Liu, 2008). Considering this, developing a highly structured method of data collection is inappropriate for this study, as a structured data collection method cannot allow for the variety of contextual factors which impact a care decision for patients. Therefore, surveys and structured interviews are considered inappropriate. To allow for the variation of contextual factors that will impact a decision, a semi-structured interview guide was developed. Furthermore, to give context to how effective nurses considered the NEWS Chart to be for each construct identified in the kernel knowledge, five-item Likert scales were used. For the Likert scales, a score of '1' meant that it did not help at all, with '5' meaning it was very helpful. The same five-item Likert scales were then used to compare the NEWS Chart to the legacy vital sign charts that would have been used.

This interview guide was developed to establish how well the design-principles instantiated in the Irish HSE's NEWS Chart facilitate the information-processing tasks identified in the kernel knowledge. A two-phase interview refinement process was conducted based on a pre-test and pilot of the interviews with a representative sample of 4 participants. This phase provided some insight into how nurses use the NEWS Chart to assist their clinical reasoning processes, as well as allowing the interviewer to become more practised in speaking with health professionals. During this phase it was established that there was a necessity to present practical examples of the information processing tasks to facilitate conceptual comprehension of the questions (See appendix 4 for these examples). Having adequately refined the interview method, interviews were conducted with 8 nurses with an average of 21

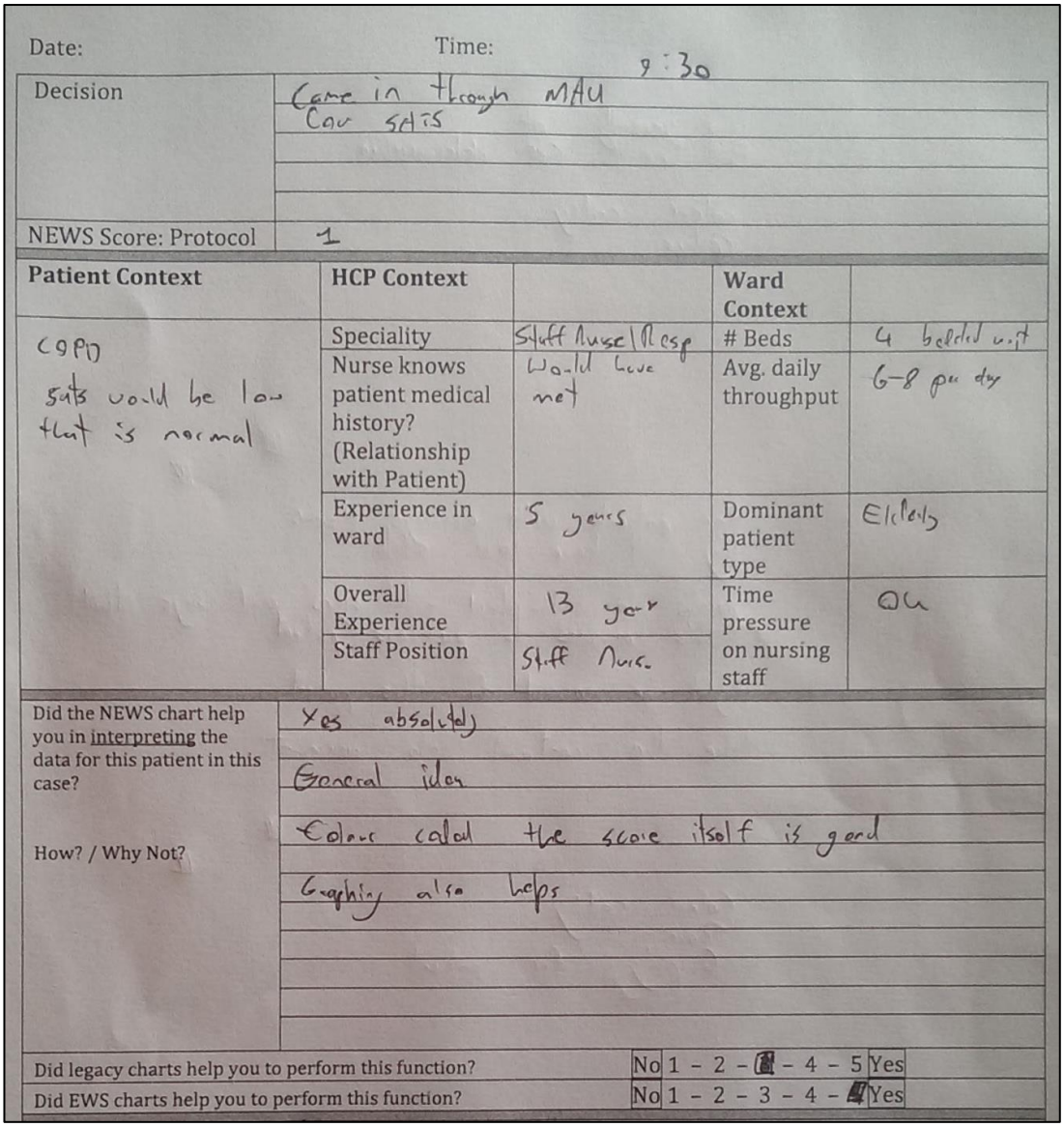
years of experience in nursing and with experience of using the NEWS Chart as an important tool that aids their clinical reasoning process (See Appendix 5 for interview guide script).

4.2.3. Method of Analysis

Data analysis was performed after the interviews were completed. Interviews were recorded using a voice recorder and notes were kept on the interviews using an interview guide (See appendix 5 for interview guide). Analysis of the interviews began by transcribing all interviews and the interview guides for each nurse were scanned and attached to the associated word document. Analysis of the interview data then followed the process of data reduction, data display and conclusion drawing as outlined by Miles & Huberman, (1994b).

4.2.4. Method of Data Reduction

Data reduction can be defined as the process of selecting, focusing, simplifying, abstracting and transforming the data collected in interviews (Miles & Huberman, 1994b). Having transcribed the interviews, they were read and listened to a number of times to become familiar with the subject matter and the emergent themes. It was found that; in general there was little divergence in answers provided for questions, however, some nurses were able to provide more insight into how well the NEWS Chart performed and the role system features played in helping them to process patient information. Based on the interviews, five word documents were developed which contain answers relevant to each of the information processing tasks identified in the kernel knowledge. These interviews were then analysed and Concept Centric Matrixes were developed for each information-processing task. A column was created for each design principle identified in the interviews and a row was added for each nurse. For each interview in which a design principle was identified as being useful for facilitating a particular information-processing task, the ‘number 1’ was allocated to the appropriate cell. On completing this process, the data was analysed to establish the design principles that had the highest perceived usefulness for each information-processing task. Figure 4.1 presents an extract from an interview guide.



Date: Time: 9:30

Decision	Came in through MAU Cav sats
NEWS Score: Protocol	1

Patient Context	HCP Context		Ward Context	
COPD sats would be low that is normal	Speciality	Staff Nurse/Resp	# Beds	4 bedded unit
	Nurse knows patient medical history? (Relationship with Patient)	Would have met	Avg. daily throughput	6-8 per day
	Experience in ward	5 years	Dominant patient type	Elderly
	Overall Experience	13 year	Time pressure on nursing staff	Ok
	Staff Position	Staff Nurse		

Did the NEWS chart help you in interpreting the data for this patient in this case? How? / Why Not?	Yes absolutely General idea Colour coded the score itself is good Graphing also helps

Did legacy charts help you to perform this function?	No 1 – 2 – [redacted] – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – [redacted] Yes

Figure 4.1. Extract from interview guide

4.2.5. Results – Data Display

The purpose of data display is to compress the major findings from the data analysis in a clear and adequately comprehensive manner. This study uses the form of a narrative text, with analysis of the concept centric matrixes (CCM) and the Likert scales used to summarise the findings and indicate the performance of the NEWS Chart compared to the legacy systems. This is consistent with the approach employed by Appleton, (1995). From analysis of the interviews, 2 design principles emerged as having an impact on nurse's clinical reasoning, these were; the ability to physically compare multiple charts and presentation of the EWS score.

Figure 4.2 presents an extract from a CCM used to analyse design principles that nurses perceived as having an impact on their ability to interpret vital sign data presented on observation charts.

	Design Principles Mentioned									
Nurse #	Colour Coding	Graphing Vital Signs	Seperating Vital Signs	Standardised Charts	Instructions on use	Preferential presentation of more	Using multiple charts	Presentation of the EWS Score	**EWS Rating**	**Legacy System Rating**
Nurse 1	1	0	1	1	1	0	0	1	4	1
Nurse 2	1	1	0	0	0	0	0	1	5	3
Nurse 3	1	0	0	1	1	0	0	0	5	3
Nurse 4	1	1	0	0	0	0	0	0	5	2
Nurse 5	1	0	0	0	1	0	0	1	3	1
Nurse 6	1	0	0	1	0	1	0	1	5	3
Nurse 7	1	1	1	1	0	0	0	1	5	3
Nurse 8	1	1	1	1	0	0	0	1	4	3
Percentage	*100*	*50*	*37.5*	*62.5*	*37.5*	*12.5*	*0*	*75*	*4.5*	*2.375*

Figure 4.2. Extract from CCM.

The design principles of colour coding, graphing vital signs, separating vital signs, standardisation of chart design and the presentation of the EWS score were perceived by nurses as being the most useful design features. Analysis of the CCM demonstrates that the number of times the following design features were identified by nurses as having an impact on specific information processing tasks:

- Colour coding - 24 times,
- Graphing vital signs - 17 times,
- Separating vital signs - 13 times,
- Standardised charts - 14 times and
- Presentation of the EWS score - 19 times.

Table 4.4 presents an extract from analysis of the concept centric matrixes, which demonstrates how often particular system features were identified as having an impact on the information processing tasks. Having reviewed the interview scripts a number of times; the data provided by Table 4.4 presents a fair summary of the tone of the interviews.

Percentage of Nurses Who Found Design Principle as Useful								
Information Processing Task	**Colour Coding**	**Graphing Vital Signs**	**Separating Vital Signs**	**Standardised Charts**	**Instructions for use**	**Preferential presentation of information**	**Using multiple charts**	**Presentation of EWS Score**
Interpreting	100.00	50.00	37.50	62.50	37.50	12.50	0.00	75.00
Discriminate	75.00	25.00	50.00	25.00	12.50	37.50	0.00	37.50
Relationships	25.00	62.50	37.50	25.00	12.50	12.50	0.00	25.00
Match	25.00	25.00	12.50	37.50	12.50	0.00	37.50	37.50
Predict	75.00	50.00	25.00	25.00	0.00	0.00	0.00	62.50

Table 4.4. High-level analysis of interviews.

Colour coding was identified as having a significant impact on nurse's ability to interpret vital signs, discriminate between more and less important vital signs and predicting patient outcomes. Colour coding was identified by all nurses as being useful for helping them to interpret the patients' vital signs, with nurses stating that:

> *"Well obviously, because of the colour-coding, if it's high up in the pink, the pink will always give you an idea"* and
>
> *"Well, basically I find these charts excellent because of the colour coding…. So you know immediately when you have an abnormality."*

For discriminating, colour coding was found to be an effective way of highlighting individual vital signs that are problematic with a nurse stating that:

> *"The colour coding helps…you can see straight away blood pressure…you look at the grey, then you look at the colour… you can see that you have a high EWS from the colour."*

Graphing of vital signs was found to have an impact on all of the information processing tasks, with its most significant impact being on helping nurses to identify relationships or patterns in vital sign data.

> ***Interviewer****: "Did the design of the chart help you to identify relationships or patterns for this patient?"*
>
> ***Nurse****: "It can do yeah, for example if you have a patient who comes in with a chronic lung problem and you know their SATS are sitting at 85 or whatever, that could be normal for him, so therefore, you don't need to jump up and down about it as much as a patient without a chronic lung problem. So it prompts you by looking at it, the patterns of it, as to what you need to do".*

This quote implies that the graphed chart can act as a source of information for nurses. In this scenario the nurse could look at the pattern of vital signs for a patient and see that high oxygen saturation is normal for this patient, therefore allowing the nurse to make an appropriate care decision for the patient.

Separating vital signs was also found to have an impact on all information processing tasks with it having the most significant impact on allowing nurses to

discriminate between more and less important vital signs. This is logical as without separating the vital signs it would be difficult to distinguish between each of these scores.

> *"Yes I think you can (discriminate between data), if you look at the different sections… you can pin point it straight away".*

Standardised charts also had an impact on all information processing tasks, with it having the most significant impact on interpreting and matching situations. A standardised chart allows rapid interpretation of vital signs, as nurses are already familiar with the format of the NEWS chart it minimises time spent trying to understand the chart, allowing the nurse to begin understanding the data as soon as possible.

> *"I think the standardisation is really important because we would be transferring anyone we can't manage here in to Limerick…you want them all to be the same (the charts used)… when they get transferred this document would go with them".*

Presentation of the EWS Score was a design prescription not highlighted in literature, the importance of this as a design prescription became apparent from interviews, with 75% of nurses highlighting its usefulness in helping to interpret vital signs, with it also having a high impact on nurses ability to predict patient outcomes. This is logical as there is a close link between interpreting the state of a patient's health and the likely outcome for the patient. When questioned on interpreting patient's health, one response stated:

> *"Because the minute you tot up the score at the end, it immediately jumps out to you that you maybe should be watching out for something".*

Instructions for use were found to have an impact on interpreting vital signs. Introducing instructions for using the chart will help nurses who are not familiar with the chart to learn how to use it and what protocols should be followed if a patient records a particular score. When comparing it to the legacy systems, one nurse stated:

"It's much more informative and it tells you about contacting the doctor and the protocols for care, it's very informative".

This section has so far identified how the design principles instantiated in the NEWS Chart have impacted the information-processing phase of clinical reasoning and analysis of the Likert scales demonstrate that the nurses interviewed perceive the NEWS Chart as being superior to the legacy systems in place. It would be preferable to perform a like-for-like analysis of the legacy systems compared to the NEWS Chart, however, a characteristic of the legacy systems was the non-standardisation of the systems used. Nurses cited that

"Before you would have had a separate chart for different things. You would have a pain score chart, your urine analysis would be somewhere else, you know, here they are all together".

While nurses in general accepted there that was a benefit to the legacy systems, they perceived the NEWS chart as having a superior impact on their ability to process vital sign information:

"There is no comparison really, there was paperwork and it was beneficial obviously, there was monitoring, but you couldn't… it wasn't in your face".

This is reflected in the analysis of the Likert scales presented in Figure 4.3, with nurses perceiving the NEWS chart to be superior in facilitating each of the information-processing tasks discussed.

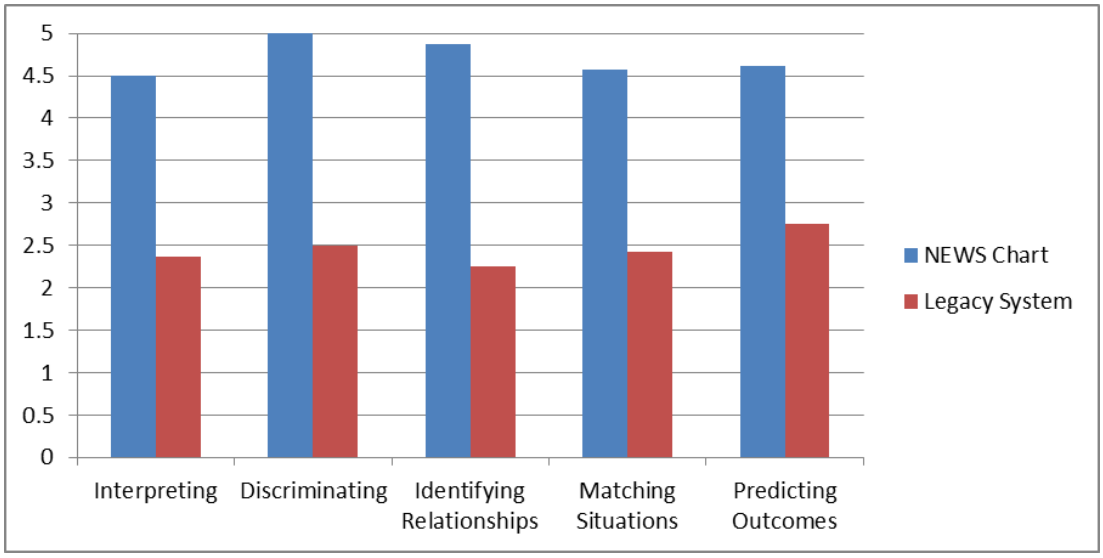


Figure 4.3. Average Likert score for each construct

4.2.6. Discussing the Evaluation of the NEWS Chart

The purpose of this research phase was to identify the design knowledge embedded within the Irish HSE's NEWS Chart and to establish the utility of the NEWS Chart in terms of its purpose. It was established that the problem system the NEWS Chart was designed to affect was the identification of patients at risk of deterioration and a number of system features were identified in the NEWS Chart that were designed to manipulate the problem system and affect the required change. This knowledge allowed for the formalisation of the framework for REVIEWS version Alpha, which in turn served as the basis for developing the evaluation protocol for this study.

The data gathered from the interviews with nurses experienced in using the NEWS Chart demonstrated that the NEWS Chart was perceived by nurses to be superior to the legacy systems they used in terms of facilitating the data-processing phase of clinical reasoning. The data also demonstrated the effectiveness of particular design features such as the colour coding of the chart and standardising the design of the chart. Furthermore, it was possible to establish which design features that had a significant perceived impact on each of the tasks of the information-processing phase of clinical reasoning. For example: it was possible to demonstrate the impact colour coding had on interpreting vital sign data and discriminating between relevant and irrelevant information for the patient.

As noted in the introduction to this research phase, there was a necessity to acquire and synthesise the design knowledge for observation charts, as little documentation existed explaining the purpose of specific design features. Furthermore, previous efforts to quantify the effect of these design principles used quantitative data collection methods. This form of objective data collection is not likely to capture the complexity of decision making in complex clinical settings. By employing a semi-structured interview method and by interviewing nurses with an average of over 21 years of experience, this study allowed for the participants to call on their vast experience of clinical reasoning to establish what system features were most important for them and how they used particular system features to assist them when processing vital sign information for individual patients.

4.2.7. Applying this knowledge to the updated DSRM process Model

As established in section 3.3.3.1, this research is to use the updated DSRM process model to structure the research design. In the case of discovering design knowledge embedded in situated artefacts for which little formalised design knowledge exists there is a necessity to introduce an inductive approach for discovering and synthesising design knowledge for each of the phases of the updated DSRM process model. The purpose of this section is to reconcile the approach presented in section 4.2.1 with the design phases of the updated DSRM process model. This is presented at a high level in Table 4.5

Updated DSRM Process Model Phases	**Design Knowledge Discovered**	
1. *Develop the utility requirements*	*eNEWS Problem Environment.*	• Early Identification of acute illness in patients.
	Required Changes in problem environment to be made by eNEWS.	• Provide easier recognition of patient data. • Aid identification of abnormal clinical parameters for patients.
2. *Develop the kernel knowledge*	*5 dominant information processing tasks performed during clinical reasoning.*	• Pattern recognition. • Interpreting cues. • Matching previous situations. • Relating Information. • Predicting Outcomes.
	6 meta-design principles identified on AWTTS charts which impact information processing tasks.	• Colour coding, • Standardisation of chart design, • Graph vital signs statistics, • Separate all vital signs recorded, • Preferential presentation of information perceived to be more important and • Instructions to use chart included on same page as chart.

Updated DSRM Process Model Phases	Design Knowledge Discovered	
3. Design and development	The framework for REVIEWS (Version Alpha) is presented in Table 4.3 in section 4.2.1.5. The tentative design theory leverages knowledge relating to the utility requirements, the kernel knowledge and empirical evidence relating to the physical design of the NEWS chart to formalise a design theory. This design theory will inform the evaluation protocol.	
4. Demonstration	4 Design principles identified as being instantiated in the paper-based NEWS chart.	• Standardised approach to chart design. • Colour coding of vital signs. • Graphing of vital signs. • Graph each vital sign separately.
5. Evaluation	Semi-structured interview method employed to comparatively evaluate the Irish HSE's paper-based NEWS chart and legacy charts nurses would have had experience of using. The evaluation demonstrated that nurses perceived the NEWS chart as being superior to legacy charts. Analysis of the findings allowed for the identification of a number of design principles that had not been considered from literature. This knowledge will contribute towards the next iteration of the framework for REVIEWS.	
6. Communication	The methodology, research approach and design knowledge used for this research phase are communicated in this thesis, with the knowledge formalised useful for further refinement of the design theory.	

Table 4.5. Design Knowledge captured for the Irish HSE's paper-based NEWS chart.

4.3. Phase 2: A Comparative Evaluation of the Utility of an Electronically Generated Patient Vital Sign Chart over a Paper Based Chart

In 2013 the Health Information Systems Research Centre (HISRC) in University College Cork, Ireland developed a version of the Electronic National Early Warning Scorecard (eNEWS). The mobile software solution was designed to capture patient vital sign data that is currently recorded on paper using the Irish Health Service Executive's (HSE) paper-based National Early Warning Scorecard (NEWS). The NEWS system is an example of an Aggregate-Weighted Track-and-Trigger System (AWTTS). An AWTTS is designed to help health professionals to identify patients at risk of deterioration by assigning weighted scores to vital signs and establishing baseline care protocols for the aggregate of these scores, (Prytherch et al., 2010). However, problems have been identified in the use of paper based AWTTS, (Prytherch et al., 2010). These problems include the utility of the AWTTS in terms of predicting patient deterioration, (G. B. Smith et al., 2008) maintenance of patient records and the possibility for human error when recording vital signs and calculating the AWTTS scores, (Johnson et al., 1993; Kyriacos et al., 2011).

While eNEWS was designed to improve the accuracy and completeness of patient vital sign data capture and improve the accuracy of the calculated early warning score, (Donoghue et al., 2011) the chart on which the data is presented serves as more than a tool for recording vital sign data. The chart also represents the primary means of presenting the vital sign data to the user. Section 4.2 presents a comparative evaluation of the paper-based NEWS chart compared to legacy vital sign charts and establishes that the design of the NEWS chart was perceived by nurses to be more useful than legacy vital sign charts in terms of facilitating the information processing tasks associated with clinical reasoning.

Research has demonstrated that information presented to health care professionals plays an important role in the clinical reasoning process, (da Silva Bastos Cerullo, 2010; Greenwood & King, 1995; Levett-Jones et al., 2010). While some disagreement exists in literature regarding the definition of this phase, the previous evaluation of the paper-based NEWS chart, (Creedon et al., 2014) establishes the

tasks of: *pattern recognition*, *interpreting cues*, *matching previous situations* and *relating information* to be the most common tasks associated with information processing during clinical reasoning. Figure 4.4 presents an extract from the paper-based NEWS chart, this chart is based on a sample case used for training on how to use the system provided by the Irish HSE.

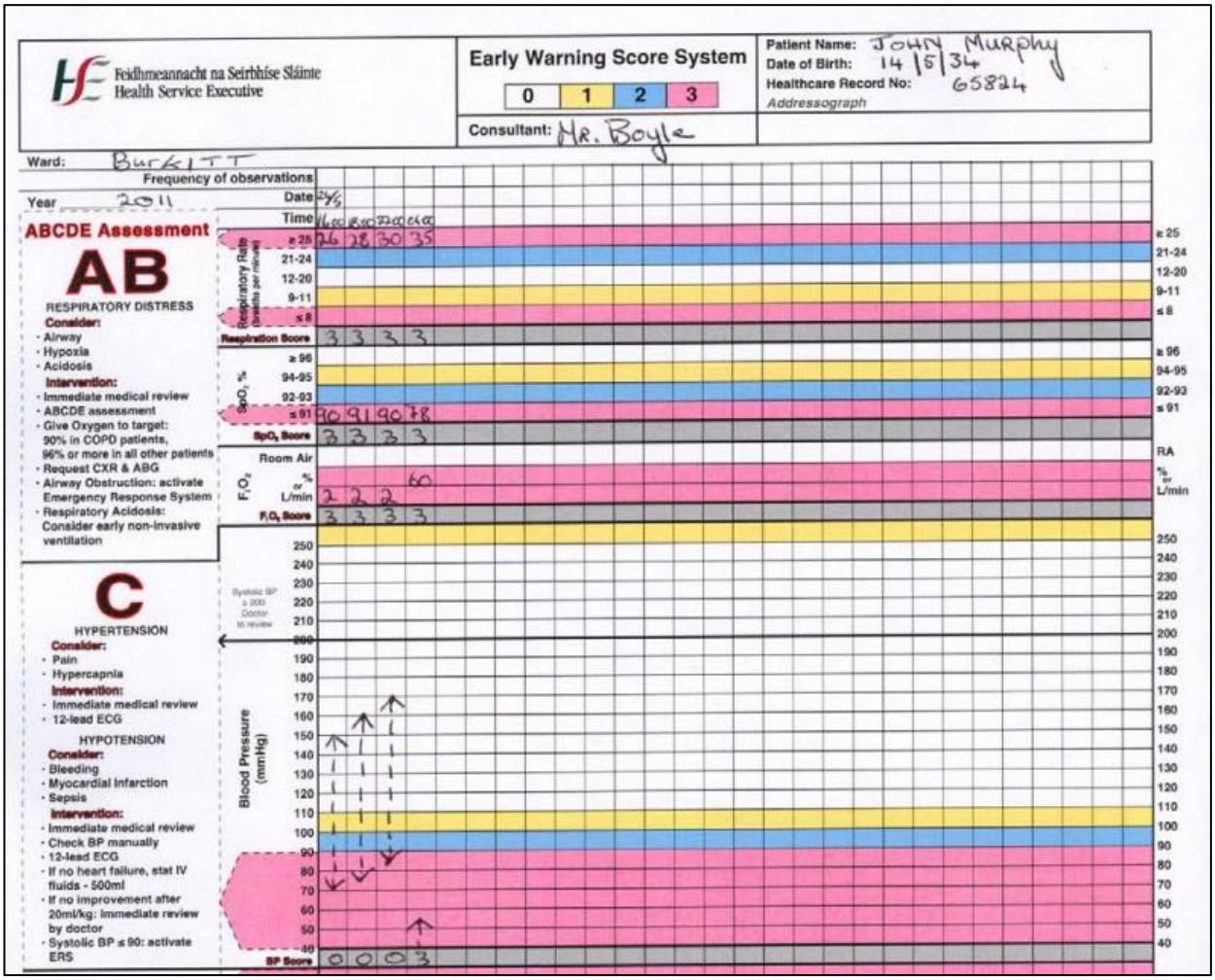


Figure 4.4. Extract from paper-based NEWS chart Source: http://www.hse.ie/eng/about/Who/clinical/natclinprog/acutemedicineprogramme/earlywarningscore/Case%20Study%201.pdf.

Evaluation of the paper-based NEWS chart represented the first data-gathering phase of this research project and from this phase the framework for REVIEWS version Alpha was formalised. This section represents the second data gathering phase. The purpose of this framework is to establish a design theory for presenting patient vital sign data on electronically generated AWTTS charts in a manner which facilitates

the information processing tasks associated with clinical reasoning, i.e. pattern recognition, interpreting cues, matching previous situations and relating information.

In order to adequately evaluate the electronically generated eNEWS chart, there is a necessity to retrospectively investigate the design of the eNEWS chart. This process will establish the purpose and scope of the eNEWS chart and will ensure that the comparison with the paper-based NEWS chart is in fact like-for-like. As such, the structure of the following sections will follow the structure of section 4.2 where an approach for discovering and synthesising design knowledge for situated artefacts (as presented in section 3.4.1) is first employed to formalise the design knowledge embedded within the eNEWS chart, followed by a comparative utilitarian evaluation of the chart. The knowledge discovered during these steps will allow for iterative refinement of the framework.

Having established a method for comparatively evaluating the perceived utility of observation charts in respect to facilitating processing of vital sign information in a previous study, this section presents the methods employed and the findings of comparing the utility the paper-based NEWS chart and the electronically generated eNEWS chart. The findings of this phase represent a significant data-gathering phase for the framework for REVIEWS. This phase presents evidence of design features instantiated in the electronically-generated eNEWS chart which have positive and negative impacts on the information processing tasks associated with clinical reasoning, as well as providing secondary findings regarding practical implications of using an electronically generated chart rather than a manually completed paper-based chart. Furthermore, to the best knowledge of the authors this study is the first that directly compares the utility of an electronically generated AWTTS chart to that of a paper-based chart.

4.3.1. Design of the eNEWS Chart

Prior to evaluating the utility of an artefact, there is a necessity to develop a formal understanding of the purpose and scope of said artefact. Evaluation of an artefact requires knowledge pertaining to the problem environment the artefact is designed to impact, the required change in the problem environment and the design features which were instantiated within the artefact that affect this required change, (Carlsson

et al., 2011; Gregor & Jones, 2007). In order to discover the design knowledge embedded within the instantiation, (Kuechler & Vaishnavi, 2008) and the utility of the design features instantiated within the system, (Markus et al., 2002) a five step design knowledge discovery and synthesis process is used to formalise this knowledge. The process as presented in section 3.4.1 is a procedural approach for synthesising embedded design knowledge and is employed to formally synthesis this design knowledge embedded within the eNEWS chart. This approach is presented in Table 4.6 as well as methods suitable for knowledge synthesis at each phase.

Design Phase	Description of Design Phase	Inductive Methods
1. Develop the utility requirements	Identify the purpose and scope of the class of artefact being evaluated. Identify the problem system and the required changes in the problem system, (Carlsson et al., 2011)	Exploratory data gathering. Literature search.
2. Develop the kernel knowledge	Formalising Kernel Knowledge allows for a deeper understanding of the problem system. Identify the theories which will govern the design process, (Walls et al., 1992) Constructs identified in kernel knowledge, are to be manipulated by the system features. Establishing feasible objectives for the design solution based on knowledge developed.	Exploratory data gathering. Review of academic and industrial literature. Creative process of adapting kernel knowledge to identify likely objectives.
3. Design and development	Create the design artefact. Artefact may be a construct, model, method or instantiation.	Creative process of reflecting on literature and analysing the artefact to abstract design principles.
4. Demonstration	Demonstrate how the design theory formalised in the previous phase can be practically instantiated. Present the process for translating the design principles into design features.	Present the process for instantiating the design theory.
5. Evaluation	Informed by kernel knowledge and problem and motivation. Establish the design principles that have been instantiated within the artefact to be evaluated. Evaluation will establish whether these design principals affect the required change in the problem system.	Semi-structured interview is conducted to evaluate artefact based on its intended utility.

Table 4.6. The approach for reflectively discovering and synthesising embedded design knowledge for this research project.

It is appropriate to employ this approach to discover and synthesise the design knowledge embedded within the eNEWS chart. Having presented the formalised design knowledge for the eNEWS chart, the knowledge will then be reconciled with

the updated DSRM process model as presented in section 3.3.3.1. The following section outlines the methods employed to discover the design knowledge for each phase of the approach, as well as the key findings from each phase.

4.3.1.1. Design Knowledge Embedded within eNEWS

As per phase 1 of this research, this phase will employ the steps for retrospectively discovering and formalising design knowledge embedded in situated artefacts as presented in section 3.4.1. It was confirmed from discussion with the designer of the eNEWS chart Dr Simon Woodworth, that the eNEWS chart was designed to mimic the functionality of the paper-based NEWS chart. As such, much of the knowledge pertaining to the utility requirements and the kernel knowledge presented in section 4.2 will be applicable to the design of the eNEWS chart. However, due to the nature of the electronic chart and the fact that the eNEWS chart is in the early stages of development, there are some design differences between the paper-based NEWS chart and the eNEWS chart. Furthermore, the evaluation of the paper-based NEWS chart elicited some useful information that contributes towards the formalised knowledge about the design of the chart. Table 4.7 presents the design knowledge that emerges from the five steps for retrospectively discovering and synthesising design knowledge embedded within the eNEWS charts.

Step 1: Identify the Utility Requirements		
Method Employed	*Findings*	
Interview with designer. Review of paper-based NEWS design.	*eNEWS Problem Environment.*	• Early identification of acute illness in patients.
	Required Changes in problem environment to be made by eNEWS.	• Provide easier recognition of patient data. • Aid identification of abnormal clinical parameters for patients.
Step 2: Identify the Kernel Knowledge		
Method Employed	*Findings*	
Literature review using a Concept Centric Matrix.	*4 dominant information processing tasks performed during clinical reasoning.*	• Pattern recognition. • Interpreting cues. • Matching previous situations. • Relating Information.
Step 3: Establish Meta-Design Principles		
Method Employed	*Findings*	
Literature review using a Concept Centric Matrix and review of paper-based NEWS design.	*6 meta-design principles identified on AWTTS charts which impact information processing tasks.*	• Colour coding. • Standardisation of chart design. • Graph vital signs recorded. • Preferential presentation of information perceived to be more important. • Instructions to use chart included on same page as chart. • Facility to compare multiple charts. • Presentation of EWS score.

Step 4: Analyse the demonstration		
Method Employed	*Findings*	
Review of paper-based NEWS design. Physical comparison of NEWS and eNEWS chart designs. Interview with eNEWS chart designer. Figure 4.4 presents an extract from the eNEWS chart.	*Design features instantiated on both NEWS and eNEWS charts.*	• Colour coding. • Standardisation of chart design. • Graph vital signs. • Separate all vital signs. • Separate all vital signs. • Preferential placement of information perceived to be more important. • Facilitate comparison of multiple charts. • Presentation of the EWS score.
	Design Features instantiated on NEWS chart, but not on eNEWS chart.	• Instructions for Use.

Table 4.7. Methods and findings for each phase of approach for retrospectively discovering and synthesising design knowledge embedded in situated artefacts.

Table 4.7 represented the design knowledge and the methods used to discover the design knowledge embedded in the HISRC's electronically-generated eNEWS chart. The next step of this phase is to present the tentative design theory. Section 4.2.1.5 presented the initial iteration of the framework for REVIEWS. As established in section 4.2.1.5 the framework that emerges from an inductive design knowledge discovery process must be seen as tentative as the design theory is based on assumptions of a design theory that has not yet been adequately tested, as such, it is open to change. However, the tentative design theory is useful as it represents the current state of the understanding of the design theory for an artefact. The following section will present the second iteration of the framework which will leverage the design knowledge as presented in this section.

4.3.1.2. The Tentative Design Theory - The Framework for REVIEWS Version Beta

The purpose of this section is to present the second iteration of the framework for REVIEWS. The initial iteration of the framework (*version Alpha*) is presented in section 4.2.1.5. Section 4.3 has thus far presented the design knowledge embedded in the eNEWS chart. This design knowledge will be leveraged to formalise the Beta version of the framework, which represents the studies current understanding of the design knowledge necessary to improve the design of electronic observation charts.

The framework (*version Beta*) demonstrates the current understanding of the impact of specific design features on information processing tasks. The extent to which design features impacts specific information processing tasks is formalised from analysis of the comparative evaluation of the paper-based NEWS chart as presented on Table 4.4. A design feature was considered to have a high impact if it was identified as being useful by 66.6% or more interviewees, a medium impact if between 33.3% and 66.5% of interviewees considered it to be useful and a low impact if greater to 0% and less than 33.2% of interviewees considered it to be useful. If 0% of users identified a specific design feature as being useful for an information processing task then it was considered to have no impact.

Design Principle		Impact on Information Process Task	Extent
1	Colour Coding of specific early warning score plot areas.	Initial interpretation of vital sign information.	**High**
		Discriminating between more and less important information.	**High**
		Identifying relationships among data points.	**Low**
		Matching analogous situations.	**Low**
		Predicting outcomes for patients.	**High**
2	Graphing of vital sign information.	Initial interpretation of vital sign information.	**Medium**
		Discriminating between more and less important information.	**Low**
		Identifying relationships among data points.	**Medium**
		Matching analogous situations.	**Low**
		Predicting outcomes for patients.	**Medium**
3	Proprietary areas for plotting vital sign data.	Initial interpretation of vital sign information.	**Medium**
		Discriminating between more and less important information.	**Medium**
		Identifying relationships among data points.	**Medium**
		Matching analogous situations.	**Low**
		Predicting outcomes for patients.	**Low**

Design Principle		Impact on Information Process Task	Extent
4	Standardised chart design.	Initial interpretation of vital sign information.	**Medium**
		Discriminating between more and less important information.	**Low**
		Identifying relationships among data points.	**Low**
		Matching analogous situations.	**Medium**
		Predicting outcomes for patients.	**Low**
5	Presentation of EWS scores.	Initial interpretation of vital sign information.	**High**
		Discriminating between more and less important information.	**Medium**
		Identifying relationships among data points.	**Low**
		Matching analogous situations.	**Medium**
		Predicting outcomes for patients.	**Medium**
6	Instruction for using chart included on interface.	Initial interpretation of vital sign information.	**Medium**
		Discriminating between more and less important information.	**Low**
		Identifying relationships among data points.	**Low**
		Matching analogous situations.	**Low**
		Predicting outcomes for patients.	**None**

Design Principle		Impact on Information Process Task	Extent
7	Preferential placement of vital signs perceived to be more important.	Initial interpretation of vital sign information.	**Low**
		Discriminating between more and less important information.	**Medium**
		Identifying relationships among data points.	**Low**
		Matching analogous situations.	**None**
		Predicting outcomes for patients.	**None**
8	Use of multiple charts.	Initial interpretation of vital sign information.	**None**
		Discriminating between more and less important information.	**None**
		Identifying relationships among data points.	**None**
		Matching analogous situations.	**Medium**
		Predicting outcomes for patients.	**None**

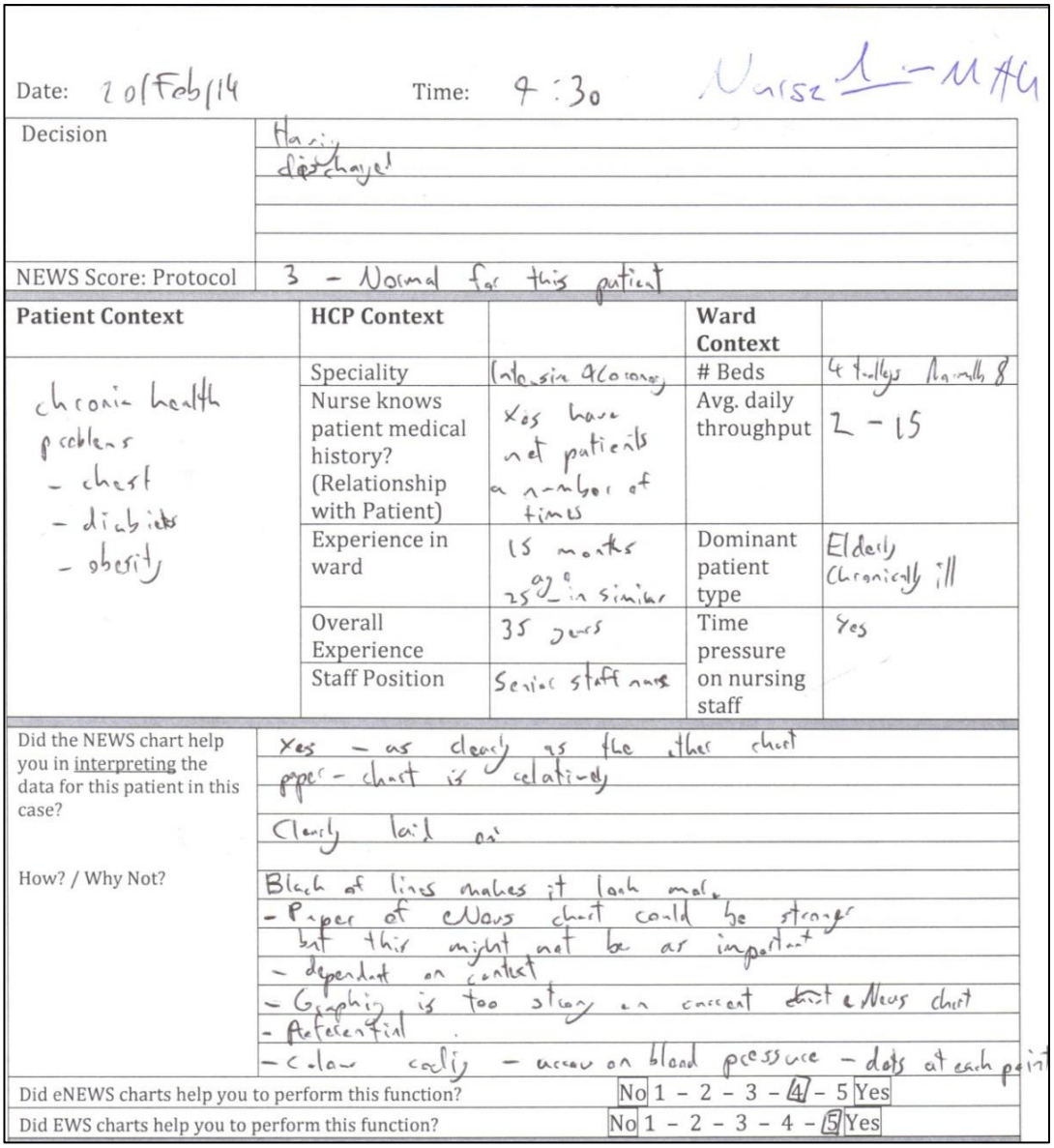
Table 4.8. The framework for REVIEWS (Version Beta)

4.3.2. Evaluation Method

Section 4.3 has thus far; established the problem environment the eNEWS chart was designed to impact, the required change in the problem environment and the design features which were instantiated to cause the required impact on the problem environment. This section will now outline the evaluation method for establishing the utility of the eNEWS chart. The purpose of evaluation is to establish how useful an artefact is in relation to the context of the problem environment, (Kazi, 2003; Scriven, 1998). In the case of the eNEWS chart, the previous section has established that the purpose of the eNEWS chart is to display vital sign data in a manner that facilitates the data-processing tasks associated with clinical reasoning, i.e. the tasks of *pattern recognition, interpreting cues, matching previous situations and relating Information* (See appendix 4 for practical examples of these tasks).

Figure 4.5. Extract from electronically generated eNEWS chart.

A qualitative semi-structured interview methodology was established for capturing the context of the decision and the design features which helped users to process vital-sign data presented on the chart. In addition to the semi-structured interviews, five-item Likert scales were included in the semi-structured interview guide to quantify the perceived utility difference between the paper-based NEWS chart and legacy vital sign charts which would have been used to facilitate the same tasks as the NEWS chart. For the Likert scales, a score of '1' corresponds to the chart not helping at all, while a score of '5' corresponds to the chart being perceived as very helpful. These scores acted as a means for the nurse to summarise how useful they perceived the chart to be and to ensure that the context of their interview answers could be understood (See Appendix 6 for interview guide script).



Date: 20/Feb/14 Time: 4:30 Nurse 1 – MA4

Decision	Having discharged
NEWS Score: Protocol	3 – Normal for this patient

Patient Context	HCP Context		Ward Context	
chronic health problems – chest – diabetes – obesity	Speciality	Intensive Coronary	# Beds	4 trolleys normally 8
	Nurse knows patient medical history? (Relationship with Patient)	Yes have met patients a number of times	Avg. daily throughput	2 – 15
	Experience in ward	15 months 25 yrs in similar	Dominant patient type	Elderly Chronically ill
	Overall Experience	35 years	Time pressure on nursing staff	Yes
	Staff Position	Senior staff nurse		

Did the NEWS chart help you in interpreting the data for this patient in this case?	Yes – as clearly as the other chart paper – chart is relatively Clearly laid out
How? / Why Not?	Black of lines makes it look more – Paper of eNews chart could be stronger but this might not be as important – dependent on context – Graphic is too busy on current chart eNews chart – Referential – colour coding – arrow on blood pressure – dots at each point
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes

Figure 4.6. Extract from interview guide.

A total of 12 nurses with an average of over 21 years of experience working as a nurse, who all have experience using the NEWS chart, were interviewed to establish the usefulness of the eNEWS chart and evaluate the utility of the eNEWS chart in comparison to the paper-based NEWS chart. Comparative evaluation has been identified as means of establishing similarities and differences in systems, (Przeworski, 1987; Ragin, 2014; Vartiainen, 2002) and comparing the utility of the design of the eNEWS and NEWS chart can allow us to further establish the utility of the design principles instantiated in both charts as well as the utility of design principles which have not been instantiated in both charts.

4.3.3. Method of Analysis

Data analysis was performed after the interviews were completed. Interviews were recorded using a voice recorder and notes of each interview were kept using an interview guide. The first phase of interview analysis process was to transcribe all interviews. The interview guides for each interview then was scanned and attached to the associated word document. Analysis of the interview data then followed the process of data reduction, data display and conclusion drawing as outlined by Miles & Huberman, (Miles & Huberman, 1994a). Figure 4.7 presents an extract from a CCM used to identify differences in design features that nurses perceived as either having a positive, negative or neutral impact on their perceived ability to identify relationships in vital sign data presented on the NEWS and eNEWS charts.

		Comparison of eNEWS and NEWS										
		Positive of eNEWS				Negative of eNEWS	Neutral					
Nurse #	Did it help? 1=yes 0=no	Presentation of more accurate data	Standardisation of use	Superior presentation of time and date	Bold graph line		Graphing	Presentation of EWS score	Presentationof time	Colour coding	**eNEWS**	**NEWS**
Nurse 1	1						1	1	1		5	5
Nurse 2	1	1	1				1				5	4
Nurse 3	1				1		1				5	4
Nurse 4	1				1		1			1	3	4
Nurse 5	1				1					1	4	4
Nurse 6	1			1	1						4	3
Nurse 7	1	1	1				1			1	4	2
Nurse 8	1						1				4	4
Nurse 9	1						1				4	4
Nurse 10	1						1				4	4
Nurse 11	1						1			1	1	4
Nurse 12	1							1			3	4
Total	*12*	*2*	*2*	*1*	*4*	*0*	*9*	*2*	*1*	*4*	3.83333	3.8333

Figure 4.7. Extract from CCM

4.3.4. Results

Data reduction is an inductive process, (David R. Thomas, 2003) which can be defined as the process of *selecting, focusing, simplifying, abstracting and transforming* the data collected in interviews, (Miles & Huberman, 1994b). Having transcribed the interviews, they were read and listened to a number of times to become familiar with the subject matter and the emergent themes. This study uses the form of a narrative text, with analysis of the concept centric matrixes and the Likert scales used to summarise the findings and indicate the performance of the eNEWS chart compared to the NEWS chart. This is consistent with the approach employed by Appleton, (1995). The prominent theme that emerged from analysis of the data is that there were similarities and differences between the two charts that positively and negatively impacted the perceived usefulness of the respective charts. As such, the following sections demonstrate similarities between the NEWS and eNEWS charts, differences which negatively affect the comparative utility of the eNEWS chart and differences which positively affect the comparative utility of the eNEWS chart.

4.3.4.1. Similarities

The purpose of this section is to demonstrate the design principles instantiated in the paper-based NEWS chart which were adequately represented in the eNEWS chart. Section 4.2.5 established that the design principles of *colour coding, graphing vital signs, separating vital signs, standardisation of chart design and* the *presentation of the EWS score* were perceived by nurses to have been the most useful design features in relation to processing vital sign information. Each of these design principles was perceived to have been adequately instantiated within the eNEWS chart, with nurses noting the *preferential positioning of vital signs, colour coding, graphing of vital signs, presentation of EWS scores and separation of vital sign* to be just as good. This was reflected in the results of the analysis of the Likert scales (Figure 4.8) where the eNEWS chart received a higher overall rating than the NEWS chart; however, the difference demonstrated an incremental improvement rather than a step change.

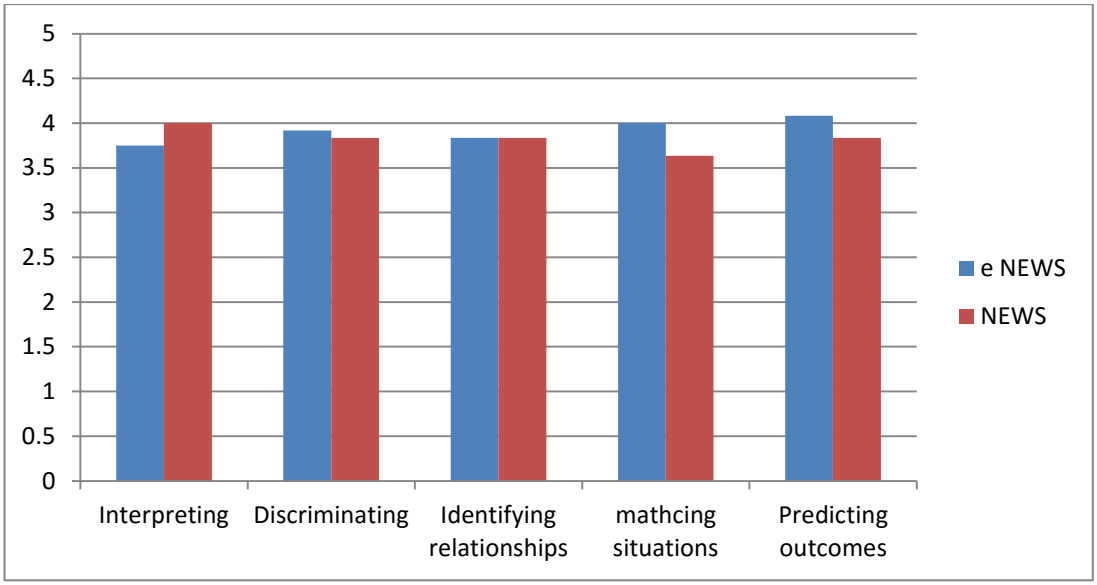


Figure 4.8. Average Likert scores from comparative evaluation of eNEWS and NEWS charts.

While the Likert scales indicate that nurses feel that the eNEWS chart was not as useful as the NEWS chart in terms of helping to interpret patient health, this is likely to be down to nurses familiarity with using the paper-based NEWS chart. This observation is consistent with Christofidis et al. (2013), who observed that *if chart users have extensive experience with one particular chart, then this familiarity might result in superior performance using that chart as opposed to a better-designed chart.* One nurse reflected this, feeling that once they became used to the newer eNEWS chart they would be just as well able to use this chart, stating:

> *"Well that eNEWS chart is very easy to understand. Sure once you're used to using that then they are pretty much the same."*

While this data indicates that the performance of the eNEWS chart is at least as useful as the paper-based NEWS chart, it is worthwhile investigating the impact that missing design features have on the usefulness of the chart, as well as what differences nurses perceive to be more useful on the eNEWS chart.

4.3.4.2. Design features which Negatively Impact Utility of the eNEWS Chart

As previously noted, the design principle of including *instructions for use* was not instantiated on the eNEWS chart. This was noted on three occasions with nurses

feeling it would have a negative impact on individuals with less experience in using the chart when interpreting the vital signs and making predictions. The physical size of the instantiated eNEWS chart was also noted by nurses as being an area where it negatively impacts the usefulness of the eNEWS chart. The paper-based NEWS chart uses an A3 size paper format, with the electronically generated eNEWS chart printed on an A4 size page, with matrix on the NEWS chart measuring 45mm X 70mm and the matrix on the eNEWS chart measuring 30mm X 60mm.

While another nurse noted that she felt that the size of the chart would cause her to spend more time looking at the chart, this nurse felt on balance that *standardisation of the use* of the eNEWS chart would counteract the negative impact of the size of the chart:

> *"I would find that easier immediately (paper-based NEWS chart), you see it's tighter... This (eNEWS chart) is tidier and it's more concise I suppose you could say."*

While 2 nurses identified the size of the chart as potentially having an impact on the usefulness of the chart, 4 nurses perceived the smaller size of the eNEWS chart print out to have a positive impact on the usefulness of the chart. While the majority of nurses found the smaller sized chart to be of benefit, there is a potential negative impact of a smaller chart for nurses who have sub-optimal eyesight. Further investigation of the impact of size of the instantiated eNEWS chart would be useful; however, the initial findings demonstrate that there are pros and cons to the current size of the eNEWS chart.

The final observations that nurses noted would have a negative impact on the usefulness is related to how the plotting of data points on the eNEWS chart deviates from best practice according to nurses who evaluated the eNEWS chart. Namely these design prescriptions were to add *numbers to data points* and to add *arrows to the blood pressure recordings*. This is consistent with Preece et al., (2013) who observed the impact of charting methods on the accuracy and speed of users when analysing EWS charts.

4.3.4.3. Design Features which Positively Impact Utility of eNEWS Chart

This section will outline the design features which interview participants observed as having a positive impact on processing vital sign information compared to the paper-based NEWS chart. The design feature which nurses observed as having the most significant impact on vital sign information processing was the use of a *bold black line to graph vital sign data*. This was observed as having a positive impact on nurse's ability to *interpret data, discriminate between relevant and irrelevant data, identify patterns and relationships and make predictions*. With nurses observing:

> *"Well, I keep drawing back to the fact that you have it in bold and it definitely helps"*

The method of graphing was also observed by nurses as being clearer than the paper-based NEWS chart and nurses reported that they would have more confidence in the data presented on the eNEWS chart as it was less likely to be input in error. This observation also indicates that *standardising how data is presented* on the eNEWS chart will also have a positive impact on the usefulness of the chart in terms of helping nurses to process vital sign information.

Furthermore, contrary to some nurses noting that lack of *instructions for use as* having a negative impact on the utility of the eNEWS chart, some nurses felt that removing the *instructions for use* had a positive impact on their ability to process vital sign data. Another seemingly contradictory finding was the impact of the size of the eNEWS chart. In the case of the interviews, the eNEWS charts were printed and the design principles were instantiated on an A4 piece of paper which is marginally smaller than the chart presented on the A3 paper-based NEWS chart. 2 nurses felt that the smaller size had a negative impact on their ability to process the vital sign information on the chart. Conversely, 4 nurses observed that the smaller size of the chart would make it easier to process the vital sign information.

Overall it is apparent that many of the design features instantiated within the eNEWS chart have a positive impact on the usefulness of the chart in terms of helping nurses to process vital sign information. Analysis of the interviews highlighted the

following design features which were perceived by nurses as having a positive impact on the information processing tasks associated with clinical reasoning:

- *Bold graph lines.*
- *Standardisation of presentation of data.*
- *Presentation of more accurate data.*
- *Smaller size.*
- *Superior presentation of time and date.*

4.3.5. Discussing the Evaluation of the eNEWS Chart

The purpose of this research phase was to evaluate the utility of the eNEWS chart in comparison to the paper-based NEWS chart currently in use. A comparative analysis of the two charts established that the eNEWS chart was designed with the same purpose and scope as the paper-based NEWS chart and replicated eight of the design principles identified as having a positive impact on the usefulness of the paper-based NEWS chart. The only design principle not identified as being instantiated on both charts was not having instructions for use included on the chart.

Having developed a formal understanding of the design of both the electronically generated eNEWS chart and the paper-based NEWS chart, it was then possible to evaluate the utility of the eNEWS chart in comparison to the paper-based NEWS chart. The interviews demonstrated that the nurses felt the eNEWS chart was more useful than the paper-based NEWS chart for 4 of the 5 information processing tasks. While design principles such as: *include instructions for use, include arrows on blood pressure plotting* and *add numbers to data-points plotted* were not replicated on the eNEWS chart, nurses considered the design features of *bold graph lines, presentation of more accurate data* and *standardisation of use* to be more than compensatory for the missing design principles.

Furthermore, there is the potential for further refining the eNEWS chart to improve its usefulness. This is consistent with the design science process where iterative design is required until an artefact is developed that is considered satisfactory. In the case of the eNEWS chart a number of design prescriptions were identified by nurses which were not instantiated in the chart which would make it more useful.

One limitation of this study was not establishing an optimal size for the AWTTS charts. Size was established as being an important design consideration with 2 nurses preferring the larger format of the paper-based NEWS chart, with 4 nurses preferring the smaller size of the electronically generated eNEWS chart. While this study found that a majority of nurses preferred the smaller size, further research into the size of the chart would help to establish an optimal size.

This study was necessary to execute in order to establish the utility of an electronically generated AWTTS chart in comparison to a paper-based chart. From a review of literature regarding the evaluation of AWTTS charts, there are no other studies that directly compare the utility of an electronic chart to a paper-based chart; as such, the findings of this research should be very encouraging for future development of electronic charts. Furthermore, the findings of this study will inform the refinement of the REVIEWS framework.

This study provides insights into the perceived utility of an electronically generated AWTTS vital-sign chart in comparison to a paper-based chart, with nurses with an average of over 21 years of experience considering the electronically generated chart to be just as useful as the paper-based chart. Furthermore, the study identifies potential areas for improving the design of the electronically generated chart. Finally the data collected in this study will make an important contribution to the refinement of the framework for REVIEWS which aims to further improve how data is visually presented to users in order to facilitate the tasks associated with information processing during the clinical reasoning process. Formalising the design knowledge embedded within the eNEWS and NEWS charts allowed for identification of design features such as; *colour coding, standardisation of chart use, accuracy and clearness of vital sign charting and matching records for individual patients.* These design features contribute towards improving the utility of AWTTS charts. eNEWS as a platform has the potential to allow further improvement in how these design features are instantiated and the next phase of this research will explore how to further optimise these design features on an electronic AWTTS vital sign chart.

4.3.6. Applying this Knowledge to the Updated DSRM Process Model

Having discovered the design knowledge embedded in the eNEWS chart and presented the evaluation and analysis of the data gathering, the purpose of this section is to reconcile the design knowledge presented in phase 2 of this research, with the updated DSRM process model as presented in section 3.3.3.1. This process was also presented in phase 1 of this research, with that design knowledge being presented in section 4.2.7.

Updated DSRM Process Model Phases	Design Knowledge Discovered	
1. *Develop the utility requirements*	*eNEWS Problem Environment.*	• Early identification of acute illness in patients.
2. *Develop the kernel knowledge*	*Required Changes in problem environment to be made by eNEWS.*	• Provide easier recognition of patient data. • Aid identification of abnormal clinical parameters for patients.
	5 dominant information processing tasks performed during clinical reasoning.	• Pattern recognition. • Interpreting cues. • Matching previous situations. • Relating Information. • Predicting Outcomes.
	6 meta-design principles identified on AWTTS charts which impact information processing tasks.	• Colour coding. • Standardisation of chart design. • Graph vital signs recorded. • Preferential presentation of information perceived to be more important. • Instructions to use chart included on same page as chart. • Facility to compare multiple charts. • Presentation of the EWS score.

Updated DSRM Process Model Phases	Design Knowledge Discovered	
3. Design and development	The framework for REVIEWS (Version Beta) is presented in Table 4.8 in section 4.3.1.2. The tentative design theory formalises a set of design principles and the extent to which the design principles impact the information processing tasks performed by nurses during the clinical reasoning process.	
4. Demonstration	*Design features instantiated on both NEWS and eNEWS charts.*	• Colour coding. • Standardisation of chart design. • Graph vital signs. • Separate all vital signs. • Separate all vital signs. • Preferential placement of information perceived to be more important. • Facilitate comparison of multiple charts. • Presentation of the EWS score.
	Design Features instantiated on NEWS chart, but not on eNEWS chart.	• Instructions for use.

Updated DSRM Process Model Phases	Design Knowledge Discovered
5. *Evaluation*	Semi-structured interview method employ to comparatively evaluate the Irish HSE's paper-based NEWS chart and legacy charts nurses would have had experience of using. While a number of design differences between the NEWS and eNEWS charts were identified, interviewees felt the superior clarity of the electronically generated eNEWS chart made up for missing design features. The eNEWS chart was considered to perform at least as well as the paper-based NEWS chart.
6. *Communication*	The methodology, research approach and design knowledge used for this research phase are communicated in this thesis, with the knowledge formalised useful for further refinement of the design theory.

Table 4.9. Phase 2 for the design of the Framework for REVIEWS employing the updated DSRM process model.

4.4. Conclusions

The purpose of this chapter was to present an understanding of the design knowledge embedded in both the paper-based NEWS chart and the electronically generated eNEWS chart. This knowledge was then utilised to evaluate how useful each chart was in the context of the problem system they were designed to impact. In order to discover and synthesise the design knowledge embedded in both charts, an approach for reflective design knowledge discovery and synthesis as presented in section 3.4.1 was employed to discover the design knowledge embedded in both the NEWS and eNEWS charts. This approach allowed for the identification of the utility requirements and kernel knowledge for each chart. It was established that the primary purpose of both the NEWS and eNEWS chart was the same. This was an important observation, as by establishing that each chart is designed to have the same impact on a particular problem system, it allows for an "apples-to-apples" comparative evaluation of the respective charts. The approach also allowed for the identification of design features which have been instantiated in each chart. As both the NEWS and eNEWS charts had some commonalities and differences in terms of instantiated design features, evaluation of each chart presented an opportunity to establish the utility of particular design features. It was necessary to perform this retrospective design knowledge discovery and synthesis approach in order to formalise the design knowledge necessary for the updated DSRM approach as presented in section 3.3.3.1. Sections 4.2.7 and 4.3.6 presented the design knowledge for the updated DSRM approach for both the paper-based NEWS chart and the electronically-generated eNEWS charts respectively.

A further finding that bodes well for the continued development of an electronically generated vital sign chart is the positive response with which nurses evaluated the electronically generated chart. A key consideration when introducing any electronic system that could potentially replace a situated paper-based system is resistance to change. However, from this research it emerged that nurses considered the eNEWS chart to be as useful as the paper-based NEWS chart. Furthermore, nurses stated that they felt there are a number of potential benefits to using an electronically generated chart. As such, it bodes well that further iterations of the eNEWS chart should also

be positively evaluated and that evolution of the eNEWS chart could result in a chart that is more useful than the legacy paper-based chart.

The design knowledge that emerges in this chapter represents significant contributions towards the final design of the framework for REVIEWS. The purpose of the framework is to ultimately formalise a set of prescriptive design principles that when adequately instantiated have a positive impact on the information processing tasks performed by nurses when using electronic observation charts. The knowledge discovery process for formalising these design principles begins with the initial two phases of this research, where the design knowledge embedded in both the paper-based NEWS and electronically-generated eNEWS charts is discovered and formalised. The comparative evaluation of each of these also contributes significant design knowledge towards the framework. In section 4.2.1.5 the initial tentative version of the framework (Version Alpha) is presented. REVIEWS Alpha represented the initial understanding of the design knowledge embedded in the paper-based NEWS chart and the knowledge presented in this version of the chart and provided the platform for developing the evaluation protocol for this research. The second iteration of the framework (Version Beta) is then presented in section 4.3.1.2. This iteration of the framework presents an understanding of the extent to which specific design features impact the information processing tasks performed by nurses. The knowledge for this iteration of REVIEWS emerges from analysis of the findings of the comparative evaluation of the paper-based NEWS chart presented in section 4.2.5.

The purpose of this chapter was to present the design knowledge embedded in both the paper-based NEWS chart and the electronically-generated eNEWS chart and to present a comparative utilitarian evaluation of each chart. This process allowed for the formalisation of significant design knowledge that will contribute towards the final version of the framework for REVIEWS. The methods used in this chapter included both inductive and empirical methods and allowed for important theorisation of both the problem space and a potential design theory. The purpose of the following chapter is to present further theorisation regarding the problem space and to identify extant literature that might allow for further refinement of the framework. This process will represent the first deductive design approach of this

research project and represents the design knowledge development stage for phase 3 of this research project. The design knowledge presented in chapter 5 will then be instantiated in V2.0 of the eNEWS chart, with this process being presented in chapter 6.

Chapter 5 : INCORPORATING DEDUCTIVE DESIGN INTO THE FRAMEWORK FOR REVIEWS

5.1 Introduction

The purpose of this chapter is to build on the embedded design knowledge discovered in phases 1 and 2 of this research (*presented in chapter 4*) and to leverage extant literature to further theorise and refine design knowledge that can allow for iterative improvement on the framework for REVIEWS. This framework will establish a set of rules which can be applied to electronically generated AWTTS charts to improve the perceived utility of the chart in terms of facilitating information processing during clinical reasoning. The framework is designed to be applicable to a class of artefact (i.e. electronic AWTTS charts). The framework will present a coherent and comprehensive set of design principles which when applied to the design of an electronic AWTTS observation chart will improve the design of the chart with regard to supporting the information processing tasks performed by nurses during the clinical reasoning process. REVIEWS will leverage both explicit theoretical design knowledge presented in literature and embedded design knowledge as formalised in chapter 4. Chapter 6 will then present a case study of how the framework can be operationalised and an evaluation of the artefact will be presented to demonstrate the utility of the framework.

5.2 A Design Science Approach for Designing, Building and Evaluating

Good design requires more than the technical capabilities necessary to develop an artefact, it also requires knowledge of the problem environment in which the artefact is to be situated (Gregor & Hevner, 2013; Niehaves, 2007; Nunamaker, Applegate, & Konsynski, 1988). This is comparable to the nature of scientific enquiry, where knowledge of the problem environment is required prior to formulating a line of enquiry. Furthermore, like scientific enquiry, good design should be repeatable and process orientated. Chapter 3 presented a number of design science research approaches, (A. R. Hevner et al., 2004; Peffers et al., 2008; Vaishnavi & Kuechler-Jr., 2008; Walls et al., 1992; Walls, Widmeyer, & Sawy, 2004), their aim was to formalise the traditional design, build and evaluate phases and establish the research

issues inherent to each stage of the process (A. Hevner & Chatterjee, 2010). However, there has been some disagreement in the literature regarding the definition of these phases and what the output of these phases should be. More recently, in an attempt to develop a coherent and end-to-end understanding of the design science process, Gleasure et al. (2012) developed the Process Model for Procedurally Transparent design science research (PMPT). The focus of the PMPT approach was to increase the transparency and therefore the perceived rigor of the DSR process. Section 3.3.2 presented a detailed exploration of the phases of the PMPT DSR approach, with the purpose of coming to an understanding of the terminology and language used to formulate the process. The PMPT approach was designed as a start to end DSR approach that allows for a deductive design approach, however, this approach is not compatible with the research presented in this thesis as this research seeks to iterate on a situated artefact with embedded design theory. The Design Science Research Methodology (DSRM) process model as formalised by Peffers et al., (2008) was identified as a suitable DSR approach for this research however, concerns were cited regarding the transparency and perceived rigor of the approach. Considering this, an updated version of the DSRM process model that incorporates some of the language employed by the PMPT DSR approach was presented in section 3.3.3.1.

As already noted this chapter presents the design knowledge necessary to design the framework for REVIEWS, as such, the structure of this chapter will follow the updated DSRM process model as far as the *design and development* phase. Chapter 6 will then present a case to demonstrate how the design theory can be instantiated and a utilitarian evaluation is performed to establish the utility of the framework. The following sections will present the design knowledge necessary to design the framework, beginning with the development of the utility requirements.

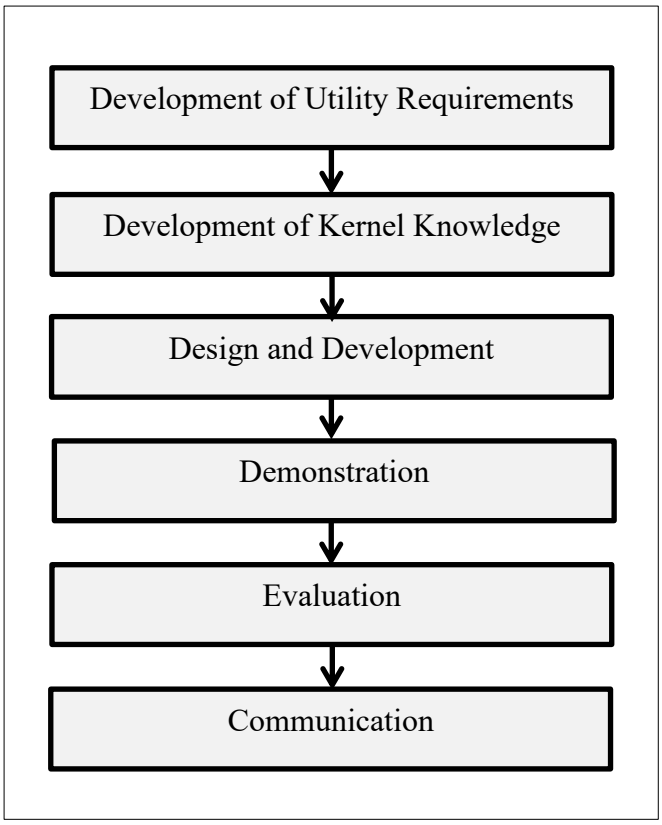


Figure 5.1. Phases of the updated DSRM process model.

5.3 Development of Utility Requirements

The purpose of the development of utility requirements is to come to an initial understanding of the purpose and scope of the artefact to be designed. That is to say, what is the problem environment the artefact is to be designed for and what are the expected changes the artefact is expected to make in the problem environment (Carlsson et al., 2011; Gleasure et al., 2012). In this case the artefact to be designed is the framework for REVIEWS, which is designed to be applicable to electronic AWTTS charts. Previous evaluations of AWTTS charts presented in chapter 4 have demonstrated that the primary function of an AWTTS is to facilitate initial assessment for acute illness and for continuous monitoring of patient's during their hospital stay (Royal College of Physicians, 2012). This represents the problem system that AWTTS systems have been designed to have an impact on. In order to facilitate this, the NEWS chart was designed to: 1) provide better presentation of patient data and 2) aid identification of abnormal clinical parameters. These changes represent the required changes in the problem system.

Previous research into the design of paper-based AWTTS charts has identified design features which can improve the speed and accuracy of abnormal vital sign identification (Preece, Hill, Horswill, Karamatic, & Watson, 2012). A paper-based chart is limited in the support it can provide in identifying abnormal trends as paper-based charts do not have the capacity to intelligently process patient vital sign data. However, electronically generated AWTTS charts have the potential to provide intelligent support through development of algorithms to identify potentially abnormal vital signs and present this data to the user in a manner which facilitates identification. As such, the purpose and scope of the framework for REVIEWS can be defined as:

Problem system	• Initial assessment for acute illness, • Continuous monitoring of patient's during their hospital stay and • Early identification of potential clinical deterioration in patients.
Required change in problem system	• Improve how data is presented in order to: o *Provide easier recognition of patient data* o *Aid identification of abnormal clinical parameters*

5.4 Development of Kernel Knowledge

Having established the purpose and scope of the Framework for REVIEWS, the purpose of developing kernel knowledge is to gain a more detailed description of the problem system. Walls et al., (1992) describe kernel theory as *theories from the natural or social sciences governing the design process itself.* That is to say that theories from natural or social science that relate to the problem system can be *applied, tested, modified and extended through the experience, creativity, intuition and problem solving capabilities of the researcher* (A. R. Hevner et al., 2004, pg. 76). In order to transparently present this process of applying, testing, modifying and extending kernel knowledge there is a necessity to transparently present this

theoretical knowledge and the logic employed to leverage this knowledge. As the framework is designed to be applicable to electronically generated AWTTS charts, it is necessary to explore literature concerned with data presentation in a manner which facilitates understanding of the data. The following section will explore the design of the AWTTS charts from the perspective of cognitive fit theory and will then discuss appropriate theories that can dictate the design of the framework.

Spriggs et al., (2014) establish that graphical displays serve two primary purposes: first to assist in the collection and organization of data and second to present summaries and descriptions of behaviour. The second of these purposes facilitates the user in establishing the relationship between dependent and independent variables, i.e. it allows the user to infer meaning between discrete variables. For example: in the case of an observation chart, it may present discreet respiratory rate data points which have been recorded hourly. A chart is designed in such a way as to visually demonstrate the quantitative difference between the observations (typically on a Y-axis) and the temporal differences between the times of the vital sign recordings (typically on the X-axis). The user is then educated on how to interpret the observation chart, allowing the user to infer information from how the discreet data points are presented on a graphical interface. As demonstrated in this case, it is logical to state that graphical displays are essentially a means of communicating the data collected to the user and assist in giving the data meaning. This is consistent with data collected in phase 1 and 2 of this research regarding how nurses use AWTTS charts to collect and maintain individual patient's vital signs and then review the chart to assist them in coming to an understanding of the patient's condition.

In the case of the eNEWS chart, the collection and organization of the data is separated from the chart, where a simple user interface has been developed to allow fast and accurate collection of the vital sign data and a database is used to organise the data (O'Kane et al., 2010). As such, the eNEWS chart's primary function now is to communicate, i.e. to present data in a manner which facilitates the user in establishing relationships between variables. Thus far the NEWS chart has taken the form of a graphical plot, this was primarily because a graphical plot allows for recording of data collection over time and the communication of the scale of the

variables recorded. Parsonson & Baer, (1978) state that the utility of a chart is in terms of its communication function *very dependent on concise, descriptive figure titles, clear identification of scale variables and scale units and data presentation that emphasizes clarity, precision and ease of assimilation*. Considering this assertion and the observation that the eNEWS system creates a separation between the collection and organization of data and the communication of the data, exploring the method by which the eNEWS chart presents recorded vital sign data can provide insight into the usefulness of its design.

5.4.1 Cognitive Fit of AWTTS Charts

As previously noted the eNEWS chart takes the form of a graphical plot, the purpose of this section is to establish whether a graphical plot is in fact the appropriate method for presenting vital sign data to the user.

Cognitive fit theory has been used to explain the results of using graphs and tables to present data to the user (Vessey, 1991), furthermore the theory has also been used to investigate why models, maps and other data visualisation methods work (Baker et al., 2009). Baker et al., (2009) summarise the findings of cognitive fit theorists by stating that:

1. *When a problem solver has a spatial task, problem solving will be more efficient and effective when a spatial representation is presented and*
2. *When a problem solver has a symbolic task, problem solving will be more efficient and effective when a symbolic representation is presented*

Vessey, (1991) describes spatial tasks as those that require the user to *assess the problem as a whole*, with the tasks requiring the user to make associations amongst data or to perceive relationships among the data points. For these tasks Vessey posits that graphs are a more appropriate method of representing data. Vessey then describes the second type of task as a symbolic task. These tasks require the user to *extract discrete and therefore precise data values.* For these kinds of tasks tables are more appropriate. Having established that the purpose of the eNEWS chart is to communicate vital sign data in a manner that facilitates making sense of the data, it is necessary to consider what type of data is being presented on the chart.

Figure 5.2. Extract from the paper-based NEWS chart.

In order to demonstrate the concepts of symbolic and spatial tasks, it is useful to consider a case which demonstrates how both of these tasks can be represented. *Figure 5.2* presents an extract from the HSE's paper-based NEWS chart, demonstrating the data values that can be represented for the respiratory rate vital sign. The bottom row of this extract highlighted in grey represents the area for the Respiratory Rate EWS score to be plotted, with the top 5 colour coded rows presenting an area for health professionals to locate and graph the specific respiratory rate over time. As previously observed in this section, cognitive fit theorists have posited that tasks performed when reading visual representations of data are either spatial or symbolic. The NEWS chart is an example of a visual representation that has been designed to support both symbolic and spatial tasks. Table 5.1 presents a brief summary of the problem system tasks the NEWS chart has been designed to address, the type of task they represent and the approach the NEWS chart has taken to representing data for this task.

Problem System Task	Task Type	NEWS Visual Representation Approach
Aid initial assessment for acute illness.	Symbolic.	An initial assessment implies observation of a discrete set of results. In this case a table style representation is appropriate. The NEWS score is used to facilitate this assessment and a table style representation is utilised.
Aid continuous monitoring of patient's during their hospital stay.	Spatial.	Continuous assessment implies observing a set of values over time. This allows the nurse to observe improvements or degradation of patient's health over time. In this case a graphical plot is an appropriate means of visual representation. The NEWS chart provides an area for plotting data points over time.

Table 5.1. Analysis of the Irish HSE's NEWS chart in terms of cognitive fit.

Table 5.1 presents examples to demonstrate the two types of tasks associated with visual representations and demonstrates how these tasks can be supported by differing styles of visual representation. Having established the utility of cognitive fit when designing a visual representation of vital sign information for AWTTS charts, it is now worthwhile considering the tasks performed by the individuals once they have extracted the data from the visual representation.

5.4.2 Sense Making and Clinical Reasoning

Section 5.4.1 establishes that a visual representation should incorporate suitable visual representation styles to match the cognitive task being performed. This sets a high level basis for how the chart should be designed, in the case of AWTTS charts, it establishes that the charts should utilise a mix of tables to represent the symbolic EWS scores and a graphical plot to represent the patient vital signs over time. The next step as identified by Baker, (2009) is to identify aspects of visual representation that can facilitate a user in making sense of the data presented. Baker describes these tasks as data exploration during sense making.

Sense making is an activity whereby individuals retrospectively extract cues from a situation to make plausible sense of the situation. It typically occurs in cases whereby the current context is perceived to be different from the expected norm, with the focus on sense making being to accept that a situation is different from the norm in order to establish an appropriate plan of action (Tsoukas & Chia, 2002; Weick, Sutcliffe, & Obstfeld, 2005). In order to demonstrate the process of sense making, Weick et al., (2005) present the following extract from (Benner, 1994, pg. 139-140), where a nurse describes her actions when caring for a baby whose condition began to deteriorate.

> ***Nurse**: I took care of a 900-gram baby who was about 26 or 27 weeks many years ago who had been doing well for about two weeks. He had an open ductus that day. The difference between the way he looked at 9 a.m. and the way he looked at 11 a.m. was very dramatic. I was at that point really concerned about what was going to happen next. There are a lot of complications of the patent ductus, not just in itself, but the fact that it causes a lot of other things. I was really concerned that the baby was starting to show symptoms of all of them.*
>
> ***Interviewer**: Just in that two hours?*
>
> ***Nurse**: You look at this kid because you know this kid and you know what he looked like two hours ago. It is a dramatic difference to you, but it's hard to describe that to someone in words. You go to the resident and say: "Look, I'm really worried about X, Y, Z," and they go: "OK." Then you wait one half hour to 40 minutes, then you go to the Fellow (the teaching physician supervising the resident) and say: "You know, I am really worried about X, Y, Z." They say: "We'll talk about it on rounds."*
>
> ***Interviewer**: What is the X, Y, Z you are worried about?*
>
> ***Nurse**: The fact that the kid is more lethargic, paler, his stomach is bigger, that he is not tolerating his feedings, that his chem strip (blood test) might be a little strange. All these kinds of things. I can't*

> *remember the exact details of this case; there are clusters of things that go wrong. The baby's urine output goes down. They sound like they are in failure. This kind of stuff. Their pulses go bad, their blood pressure changes. There are a million things that go on. At this time, I had been in the unit a couple or three years.*

This extract demonstrates the difficulty of making a care decision for a patient and also demonstrates how the nurse would search for cues that might allow them to make sense of the patient's condition. In this case the nurse cited visual cues such as patient lethargy, pallor and objective measures such as blood tests and urine output. It is this process of searching for important information that enables nurses to begin to organise information in such a way as to take appropriate action or to make a care decision for the patient. The process of searching for more information can also be defined as data exploration during sense making.

Data exploration tasks can be defined as those tasks performed when examining data without having a previous understanding of the data (Baker et al., 2009; Grinstein & Ward, 1997; Tukey, 1980). These tasks include: *making inferences, looking for outliers, observing specific data points, looking for patterns, comparing observed facts or patterns to one's own prior knowledge, drawing analogies from the context being observed to another context and generating hypotheses.* These data exploration tasks appear to be analogous to many of the tasks performed by nurses when processing information presented on observation charts as identified in chapter 4.

Information Processing During Clinical Reasoning	Sense Making During Data Exploration
Interpreting.	*Making inferences.*
Discriminating.	*Looking for outliers, observing specific data points.*
Identifying Relationships.	*Looking for patterns.*
Matching.	*Comparing observed facts or patterns to one's own prior knowledge, drawing analogies from the context being observed to another context.*
Predicting.	*Generating hypotheses about the data.*

Table 5.2. Tasks performed during information processing and sense making.

In order to support these tasks, Baker (2009) put forward a model of Aspects of Visual Representation that Affect Sense Making, which if suitably instantiated can have a positive impact on sense making. Section 5.4.3 presents this model, with the following sections exploring the rationale of this model.

5.4.3 Aspects of Visual Representation that Affect Sense Making

In order to facilitate the discovery of abnormal vital sign trends in AWTTS charts, it is desirable to reduce the cognitive load required to make sense of the data presented on AWTTS charts. Baker developed a model of aspects of visual representation that affect sense making (Figure 5.3), which if suitably instantiated can have a positive impact on an individual's sense making activities.

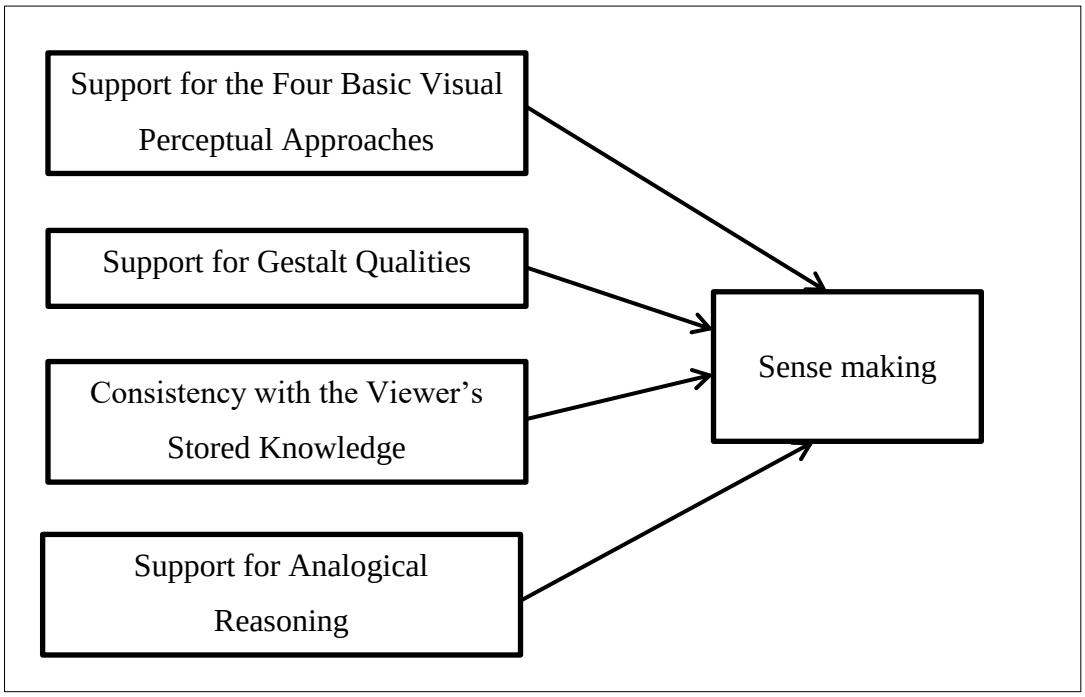


Figure 5.3. Aspects of visual representation that affect sense making. Source Baker (2009)

Prior to utilising Baker's model to guide the development of the framework for REVIEWS it is necessary to further investigate each of the aspects of visual representation that affect sense making. The following sections discuss each of these aspects and establish the applicability of Baker's model for guiding the design of the framework.

5.4.3.1 Support for the Four Basic Visual Perceptual Approaches

Bertin, (1983) observed that there are 4 basic visual perceptual approaches, with Baker et al., (2009) defining these as:

1. Association - *The viewer notes that two (or more) objects are similar, thus, can be grouped together.*
2. Differentiation - *The viewer notes that two (or more) objects are different and must be placed in different groupings.*
3. Ordered Perception - *The viewer notes that an object has more of a particular attribute than another item.*
4. Quantitative - *The viewer notes that an object has some multiple of*

Perception *an attribute possessed by another item.*

In the case of approaches 1 and 2, they can be grouped together, as it is logical to assume that different items should be placed in separate groupings. These rules can be grouped together and referred to as *Association & Differentiation.* The purpose of these visual perceptual approaches is to establish characteristics which explain how objects presented in a visual representation can be discerned. These characteristics can take the form of differences in colour, size, texture, shape and orientation (Baker et al., 2009; Bertin, 1983), with appropriate use of these characteristics said to improve the sense making experience for the user.

Ordered perception is when a viewer of data points notes that one object has more of a particular attribute than another (i.e. one item is greater or less than another). Baker et al., (2009, pg. 550) posits that *for any given set of objects in a visual representation, the greater to which objects ordered by some characteristic are perceived in their correct order, the better will be the viewer's sense making experience.*

Baker et al., (2009, pg. 537) describe the task of quantitative perception as: *the viewer noting that an object has some multiple of an attribute possessed by another item* (i.e. the ratio of one item to another). Baker posits that support for quantitative perception facilitates identification of patterns and relationships between and among objects, comparing relationships with existing knowledge and making hypotheses about the data. Bertin (1983, pg. 183) observes that support for quantitative legibility requires utilisation of *the maximum range (ratio of smallest to largest signs) in a series based on size differences.*

Considering that the purpose of the framework for REVIEWS is to facilitate the presentation of patient vital sign data and to aid identification of abnormal clinical parameters, it is worthwhile considering what the fundamental purpose of presenting vital sign data is. From a high level of abstraction the purpose of presenting patient vital sign data on a chart is to convey the meaning of patient data to a healthcare professional (Bertin, 1983; Ware, 2012). Stevens (1946), observes that in order for an individual to interpret data, there is a necessity for them to perform basic

empirical operations when reading the data. Stevens, identifies four scales which the user must process in order to make sense of the data:

1. Nominal Scale - *Determination of equality (labels)*

   Represents the most unrestricted assignment of numerals. The numerals are used only as labels or type numbers and words or letters would serve as well.(Stevens, 1946, pg. 678)

2. Ordinal Scale - *Determination of greater or less than*

   The ordinal scale arises from the operation of rank-ordering… A classic example of an ordinal scale is the scale of hardness of minerals. Other instances are found among scales of intelligence, personality traits, grade or quality of leather etc. (Stevens, 1946, pg. 679)

3. Ratio Scale - *Determination of equality of ratios*

   Ratio scales preserve relative ratios… it is permissible to multiply ratio scale data by a constant, but we may not take logs or add a constant. Ratio scale data have a defined zero, which may not be changed. (Velleman & Wilkinson, 1993, pg. 66)

4. Interval Scale - *Determination of equality of intervals or differences*

   With the interval scale we come to a form that is "quantitative" in the ordinary sense of the word. (Stevens, 1946, pg. 679)

   Interval scales involves a difference (-) instead of order (>) operator, so the set of set of permissible transformations for interval scales preserves relative differences (Velleman & Wilkinson, 1993, pg. 66).

These basic empirical operations allow an individual to determine equality, rank-ordering and the relationship amongst data, that is to say, these scales facilitate the user in interpreting data that is presented on a visual representation. In order to facilitate the user in interpreting information represented in a visual format, they

must be able to support these basic empirical operations. It is therefore necessary to consider whether Baker's four visual perceptual approaches can support Steven's basic visual perceptual approaches. This section has previously presented and defined the 4 basic visual perceptual approaches and it is worthwhile considering whether these visual perceptual approaches support the four scales for basic empirical operations. Table 5.3 presents which of the four visual perceptual approaches support the scales for basic empirical operations.

Scales	Basic Empirical Operations	Visual Perceptual Approach
Nominal	Determination of Equality.	Association and Differentiation.
Ordinal	Determination of greater or less than.	Ordered Perception.
Ratio	Determination of equality of ratios.	Quantitative Perception.
Interval	Determination of equality of intervals or differences.	***Not fully supported by the basic visual perceptual approaches.**

Table 5.3. Visual Perceptual Approaches Support for Basic Empirical Operations

The findings presented on Table 5.3 were established by logically linking the descriptions of the basic empirical operations with the descriptions of the 4 basic visual perceptual approaches. A review of Table 5.3 highlights that the nominal ordinal and ratio scales are fully supported by the 4 basic visual perceptual approaches. While it can be argued that the interval scale can be supported by ordered and quantitative perceptual approaches (i.e. rules 3 & 4), these rules do not comprehensively support the interval scale. Baker et al., (2009, pg. 543) make a similar observation, stating that: *while at least a modicum of support for the four basic visual perceptual approaches is necessary for the quality of the sense making experience, support for the four perceptual approaches is not sufficient for many data exploration tasks. While the viewer may detect differences among objects, the viewer also seeks patterns among the objects.* In order to support the interval scale there is a necessity to consider the support for Gestalt Qualities as set out in Baker's model.

5.4.3.2 Support for Gestalt Qualities

While the four basic visual perceptual approaches provide a minimum baseline for supporting sense making activities performed during data exploration, they in and of themselves do not represent an adequate level of support for facilitating the user in detecting objects and identifying patterns among the objects (Baker et al., 2009). As such, Baker posits that visual representations that demonstrate good Gestalt qualities can support this kind of activity. Based on the work of Boring, (1942), Helson, (1933) and Pomerantz & Kubovy, (1986b), Baker identified the following Gestalt qualities; *area, similarity, proximity, closure, good continuity, convexity, symmetry, colour and contrast, common fate and orientation*. Baker posits that one or more of these six laws must be present for Gestalt processing of a visual representation to occur, but it is not necessary for all to be present.

While Gestalt originally emerged from perception research, it has been extended through the whole of psychology. As such, it is necessary to clarify Baker's use of the terms Gestalt qualities and Gestalt grouping qualities. This clarification of the use of the term is necessary, as this research is concerned with human perception rather than human psychology. Furthermore, by exploring the origins of Gestalt grouping qualities, it becomes simpler to explain the qualities. The fundamental theory of Gestalt perception can be defined as the whole is more than the sum of its parts, but the perception of the whole is prior to that of its parts (Wade & Swanston, 2001). This logically implies that a whole can be perceived by an individual, without the whole of its parts being presented. Much like we can perceive an image printed in a newspaper that uses the halftone technique to simulate a continuous tone, it is possible to present isolated vital sign data points on a patient's chart to give an indication as to the patient's current or past condition. While Pomerantz identified 11 examples of Gestalt grouping qualities, these Gestalt grouping qualities can be reduced to: *proximity, similarity, symmetry, good continuation, closure* and *an occurrence of common fate*, as identified in section 5.4.3.2 (Baker et al., 2009; Pomerantz & Kubovy, 1986; Spelke, 1990; Wade & Swanston, 2001). Building on the works of Pomerantz & Kubovy, (1986) and Spelke, (1990), Baker defines these Gestalt Laws as:

1.	Similarity	*Units that are homogenous in colour and texture* (Spelke, 1990), *similar elements tend to be grouped together* (Fekete et al, 1973).
2.	Proximity	*'Nearness' or 'adjacency' in the visual field* (Brunswik & Kamiya, 1953), *things that are close together are perceptually grouped together* (Fekete et al., 1973).
3.	Symmetry	*Symmetrical visual patterns* (Bornstein, Ferdinandsen, & Gross, 1981), *two symmetrically arranged visual elements are more likely to be perceived as a whole* (Fekete et al., 1973).
4.	(Near) continuity	*Smoothly contoured* (Spelke, 1990), *visual elements that are smoothly connected or continuous tend to be grouped together* (Fekete et al., 1973).
5.	Closure	*A closed contour tends to be seen as an object* (Fekete et al., 1973).
6.	An inference of common fate	*Uniformity in motion* (Spelke, 1990).

Baker does not state that these laws are specifically designed to support the basic empirical operation of; *determination of equality of intervals or differences*, however, it is logical to assume that the stated laws of similarity, proximity, symmetry and closure can in fact have a positive impact on this task, as without being able to perceptually group elements together, it is difficult to identify the relationships between the objects, therefore making it difficult to determine the equality of intervals or differences. Furthermore, the Gestalt Laws of *(near) continuity* and *inference of common fate,* relate directly to the detection of patterns.

While the support for the basic visual perceptual approaches and the support for Gestalt properties associated with determination of intervals are relevant to the support of the basic empirical operations required to read a chart, support of pattern detection is closely related to the task of intelligent analysis of data. As such, it is possible to observe two phases in Baker's model for aspects of visual representation

that affect sense making in data exploration tasks. The first consists of approaches which support the basic empirical operations, with the second phase supporting the intelligent analysis of the data (or the application of task related knowledge to the data) prior to taking action. This is consistent with Baker et al.'s, (2009, pg. 534) definition of sense making, i.e. *the ability to comprehend complex information, assimilate it, create order from it and develop a mental model of the situation as a precursor to responding to the situation.*

Furthermore, it can be stated that; *observing the Gestalt laws of similarity, proximity, symmetry, (near) continuity, closure or an inference of common fate, when designing an electronic AWTTS chart can facilitate identification of the interval scales and the intelligent analysis of data represented on the chart*.

5.4.3.3 Consistency with the Viewer's Stored Knowledge

A common theme that has emerged from data visualisation and decision making literature is the notion that designing an interface that is consistent with a user's stored knowledge will reduce the cognitive cost associated with making the decision. Hutchins et al. (1985) observed that, the better the interface helps to bridge the gulf (between the user's stored knowledge of interfaces and that of the interface designer), the less cognitive effort needed and the more direct the resulting feeling of interaction. As the purpose of the framework for REVIEWS is to facilitate the recognition of patient vital sign data and to aid identification of abnormal clinical parameters for patients, it is logical that any design choice that minimises the cognitive cost associated with processing vital sign information should be implemented. Hutchins notes that in order to bridge the gulf between the designer's stored knowledge of interface design and the user's stored knowledge of interfaces, there is an effort required on the designer's part to learn about what the user expects.

Preece et al., (2012) observed that in cases where nurses feel the design of the chart they are currently using is very good, they are less likely to accept a chart design that deviates greatly from the design of the current chart. In the case of the paper-based NEWS chart, nurses considered this chart to perform considerably better than legacy charts they would have used. This assertion is also consistent with Christofidis et al.'s (2013) finding that when using AWTTS charts, participants with prior

experience using a specific chart were *both faster and more accurate* when recognising abnormal patient observations. Preece's observation was reflected in the evaluation of the electronically generated eNEWS chart, where a number of nurses noted that the design of the eNEWS chart was very similar to the paper-based NEWS chart and this had a positive impact on how useful the nurses considered the eNEWS chart to be. While we can observe that maintaining consistency with a user's stored knowledge when designing a chart can be useful, it should also be noted that in cases where nurses are neutral about the design of a chart, they are likely to be more accepting of a chart that is better designed.

Baker posits that by presenting data in a manner which is consistent with the user's stored knowledge, it minimises the cognitive cost associated with making sense of the data. Again this is consistent with Hutchins et al., (1985) who describes the difference in stored knowledge as *the gulf* and *the better the interface helps to bridge the gulf, the less cognitive effort needed.* As such, it can be stated that; *when designing an electronic AWTTS chart, maintaining consistency with the Viewer's Stored Knowledge in terms of the visual presentation of the data can have a positive impact on the user's ability to process information on the chart.*

5.4.3.4 Support for Analogical Reasoning

Baker posits that the previous 3 aspects of visual representation allow the user to acquire the information, with the task of analogical reasoning being the process where the user learns and discovers new meaning in data through analogical thinking. Baker presents the following description to demonstrate the process of analogical thinking:

> *A classic example of structurally consistent analogs is found in the representation of electricity as water. In the electricity/water analogy, the properties of water flow (the source analog) are used as to aid in the understanding of electrical flow (the target analog). A water reservoir maps to the electrical ground, water pump maps to a battery and a pipe restriction maps to an electrical resistor. Not only are the elements between the base and target structurally consistent, but this particular analogy allows for the mapping of inferences that*

> *range from that of pressure to voltage, current to flow rate and even the equivalency of Poiseulle's law to Ohm's law.*(Baker et al., 2009, pg. 547)

Table 5.4 describes the four main steps of analogical thinking as per Hummel & Holyoak, (2001).

Step	Description
Access	Retrieving a useful source analogy from long-term memory given a novel target problem or situation as a cue.
Mapping	Discovering the correspondences among the elements of the source and target.
Analogical Inference	Using the source to make inferences about the target.
Scheme Induction	Using the source and target together to induce a more general scheme or rule.

Table 5.4. Four major stages of analogical thinking.

This process of analogical reasoning is consistent with the task of *matching* that is conducted during information processing in clinical reasoning. Norman & Eva, (2010) describe this task as an unconscious holistic match to prior examples stored in memory. Evaluation of the paper-based NEWS chart showed some disagreement with the literature in this regard. While the process of analogical reasoning is often described in literature in terms of matching an analogous situation, nurses interviewed described the context of the patient as being very difficult to match. Nurses felt that it was not possible to match different patients with similar conditions as there were too many contextual variables which had to be considered when observing a patient. However, they did feel that it was appropriate to match a patient's current situation to their previous situation and cited the fact that they would sometimes compare a patient's chart to previous charts to see if they could learn what is normal for that particular patient. In this context it is reasonable to state that: *support for analogical reasoning can positively impact the user's ability to make sense of data presented on an interface.*

5.4.4 Applying Baker's Model to Previous Evaluations of AWTTS Charts

Section 5.4.3 explored the applicability of Baker's model of aspects of visual representation that affect sense making to the design of AWTTS charts. Having done so, it is worthwhile reflecting on the findings and considering whether Baker's model is a comprehensively adequate model on which to refine the framework for REVIEWS. The purpose of the framework is to facilitate the recognition of patient vital sign data and to aid identification of abnormal clinical parameters for patients, considering this it is necessary to evaluate whether Baker's model is appropriate to support this.

Baker's model for sense making can be divided into two phases. The first phase relates to the synthesis of data presented on an interface, with the second phase relating to the intelligent analysis of the data. As such, the first phase can be applied to any task where individual numerical data points need to be assimilated, i.e. the four basic empirical operations. The second phase is more flexible, in that it should be interpreted to suit the task that is being performed. In the case of information processing during clinical reasoning, the tasks that are performed include: *interpreting*, *discriminating*, *identifying relationships*, *matching* and *predicting*, with Table 5.2 establishing that those tasks are analogous to the tasks performed during sense making.

Additionally, previous evaluations of both the paper-based NEWS chart and the electronically generated eNEWS chart have identified design features which facilitate information processing tasks. Having explored the purpose of each of the aspects of visual representation, it is possible to map these design features to these aspects.

Approaches for Visual Representation that Impact Sense Making	Design Features Identified as Aiding Information Processing Tasks
Support for four basic visual perception approaches.	• Preferential presentation of information. • Separating vital signs.
Support for Gestalt Qualities.	• Graphing vital signs. • Colour Coding.
Consistency with user's stored knowledge.	• Standardised charts. • Instructions on use. • Presentation of the EWS score.
Support for analogical reasoning.	• Using multiple charts.

Table 5.5. Design features that logically support approaches for visual representation that impact sense making.

Table 5.5 demonstrates that Baker's model appropriately aligns to the design features that impact information processing during sense making. Having established this, it is therefore possible to draw conclusions with regard to the explanatory model for how an AWTTS chart can support the information processing tasks performed during clinical reasoning.

5.5 Design and Development

Having developed the kernel knowledge and identified the relevant theories which will govern the design of the third iteration of the framework for REVIEWS, this section will establish how these theories will be used to manipulate the problem system in order to achieve the required changes. The framework is established by considering the kernel knowledge presented in section 5.4 and reflecting on the data gathered during the evaluation of the Irish HSE's paper-based NEWS chart and the electronically-generated eNEWS chart (presented in chapter 4). This study employs the definition of design theory as per Gregor & Hevner, (2013); and Gregor, (2006), where design knowledge is formalised to give prescriptive statements for design and action, i.e. *how to do something*. While Walls et al., (1992) describes these as system features, this research adopts Markus et al.'s, (2002) more abstract perspective who

describe these prescriptive statements as *principles for selecting system features*. Iivari, (2007, pg. 46) describes prescriptive level research as research that is concerned with *how things could be and how to achieve the specified ends in an effective manner*, with prescriptive knowledge usually taking the form of *design product knowledge, design process knowledge or technical norms.* Iivari presents the following illustration for prescriptive statements:

If you want A and you believe that you are in situation B, then

- *You should do X*
- *It is rational for you to do X*
- *It is profitable for you to do X*

This section will employ a deductive design process that leverages the design knowledge discovered in phases 1 and 2 of this research, as well as the kernel knowledge presented in section 5.4 to formalise V0.1 of the framework.

5.5.1 Support for the Four Basic Visual Perceptual Approaches

The first of these phases is the interpretation of vital sign information. This phase is directly concerned with ensuring the vital sign data presented on the electronic observation chart can be quickly and accurately synthesised by the user. Section 5.4.3.1 demonstrated that support for the four basic visual perceptual approaches can support this phase. Baker identified four basic visual perceptual approaches, (i.e. *association, differentiation ordered perception* and *quantitative perception*). These visual perceptual approaches can facilitate the user in *the determination of equality, the determination of greater or less than* and *the equality of ratios*. These are fundamental tasks that a user must perform when interpreting vital sign data on an observation chart. In order to provide support of these tasks, there is a necessity to develop design prescriptions which can manipulate these visual perceptual approaches.

5.5.1.1 Association and Differentiation

Association - *The viewer notes that two (or more) objects are similar, thus, can be grouped together.*

Differentiation - *The viewer notes that two (or more) objects are different and must be placed in different groupings.*

As described in section 5.4.3.1, the visual perceptual approaches for association and differentiation can be logically linked together. Association is concerned with grouping similar objects together and differentiation is concerned with separating objects that have different properties. Therefore, it is logical to assume that if similar things are grouped together, then different things will be grouped separately.

Previous evaluations of paper-based and electronically generated AWTTS charts, have demonstrated that by separating vital sign information into distinct plotting areas, it facilitates the understanding of the data. In the case of the NEWS and eNEWS charts, this is allowed for by assigning distinct plotting areas for each vital sign recorded. This particular design prescription might seem obvious, however, it is not always the case with Preece et al., (2012) observing that health professionals have a preference to plot blood pressure and pulse together, despite this leading to a decline in performance when detecting abnormal vital signs compared to when the data points are plotted separately. As such, the first design prescription for the framework for REVIEWS can be defined as:

1a. **In order to facilitate initial interpretation of vital sign data, each vital sign should be assigned a proprietary plotting area.**

5.5.1.2 Ordered Perception

Ordered Perception - *The viewer notes that an object has more of a particular attribute than another item.*

AWTTS charts facilitate ordered perception by using the X-axis to record vital signs at a specific time. Furthermore, the use of vertical plot points at standardised unit measurements reduced the cognitive cost for the nurse to associate the data point with the appropriate time. However, in order for an individual to understand the order of the objects, there is a necessity for the user to have some knowledge with

regard to the system. While health professionals will characteristically have a high level of training with regard to understanding vital sign charts, the myriad of vital sign charts nurses have to deal with will mean that quickly achieving an ordinal understanding of the chart can be difficult.

Previous evaluations of the NEWS and eNEWS charts have demonstrated three further design features that can have a positive impact on nurse's ability to perceive the ordinal value of vital sign data points. Instruction for use being included on the chart was highlighted as being useful for nurses who have little experience in using a particular chart. Instructions for the care protocols associated with recording particular scores are important, as are instructions for helping the user to perceive the ordinal value of the vital signs recorded. This takes the form of applying colour coding to the vital sign plotting area and giving visual instruction for how to understand the colour coding system. AWTTS associate scores with individual vital signs recorded within particular ranges. In the case of the NEWS and eNEWS charts, the vital signs recorded are either associated with a score of 0, 1, 2 or 3. This gives further indication to the user in what order they should perceive the vital sign score recorded. In the case of the Irish HSE's NEWS chart, a standard of white = 0, yellow = 1, blue = 2 and pink = 3 has been set. This standard facilitates the ordered perception for users of the system (See appendix 1 for a more detailed description of the NEWS early warning score system).

A further design prescription identified by previous evaluations of AWTTS charts is to give preferential presentation to vital signs perceived as being more important. In the case of the Irish HSE's NEWS chart, respiratory distress vital signs are presented first, with nurses considering this to be the most important indicator of patient illness (Cahill et al., 2011; Oakey & Slade, 2006; Preece et al., 2013). Additionally, Bertin (1983, pg. 183) asserts that *ordered legibility only depends on the utilisation of the maximum range of ordered variables, size and value*. In order to ensure the value of the variable is communicated with the user, it is beneficial to present the number value of a data point beside where the data point is plotted. This is consistent with the observations made by nurses when evaluating the eNEWS chart. The benefits of labelling a data point were observed by Carpenter & Shah, (1998, pg. 92), who observed that the label can be used to *identify the direction, scale, unit and/or*

*referen*t. Considering the evidence presented in this section, the following 5 design prescriptions can be added to the framework for REVIEWS V0.1.

2a. **In order to facilitate the user in perceiving the ordered value of data, the date and time of vital sign recordings should be incorporated in the visual representation.**

2b. **In order to facilitate the user in perceiving the ordinal value of vital sign data, colour coding should be applied to the vital sign ranges in which scores are associated with the vital sign recorded.**

2c. **In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.**

2d. **In order to facilitate the user in perceiving the ordinal value of vital sign data, preferential placement should be given to vital signs perceived by HCPs as being most important.**

2e. **In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.**

5.5.1.3 Quantitative Perception

Quantitative Perception - *The viewer notes that an object has some multiple of an attribute possessed by another item.*

In the case of the NEWS and eNEWS charts, quantitative legibility is facilitated in a number of ways. The charts use the Y-axis to plot the value of the data point recorded, the temporal value of the vital sign recording are then represented on the X-axis. The representation of quantitative and temporal values can allow the user to observe patterns in the data. It is logical that maintaining a standardised approach to chart design should also facilitate quantitative perception. When evaluating the eNEWS chart, it was observed by a number of nurses that the chart mimicked the design of the paper-based NEWS chart and this was useful for them in terms of interpreting the information presented on the chart. As the eNEWS chart maintained

the same units of measurement as the NEWS chart, it is logical to assume that quantitative legibility will be improved.

An observation made by nurses during the evaluation of the eNEWS chart was that the chart did not have the value parameters labelled on the right-hand edge of the chart. The nurses who observed this noted this as a design flaw, this is consistent with Chatterjee et al., (2005) who observed that parameter values should be written on both sides of the chart. Considering the evidence presented in this section, the following design principles can be identified as useful when designing a chart to facilitate the quantitative legibility of a chart.

3a. **In order to facilitate the user in perceiving the ordinal value of vital sign data, vital sign values should be incorporated in the visual representation.**

3b. **In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.**

3c. **In order to facilitate the user in perceiving the quantitative value of data, a standardised approach to chart design should be employed.**

5.5.2 Support for Gestalt Grouping Qualities

While the four basic visual perceptual approaches provide a minimum baseline for supporting sense making activities performed during data exploration, they in and of themselves do not represent an adequate level of support for facilitating the user in detecting objects and identifying patterns among the objects , (Baker et al., 2009). As such, it is necessary to implement visual representations that demonstrate good Gestalt qualities. Building on the work of Boring, (1942), Helson, (1933) and Pomerantz et al., (1986), Baker identified the following Gestalt qualities: *area, similarity, proximity, closure, good continuity, convexity, symmetry, colour and contrast, common fate and orientation.* Baker posits that *one or more of these six laws must be present for Gestalt processing of a visual representation to occur, but it*

is not necessary for all to be present. As such, the following design principles which provide support for Gestalt grouping qualities can be formalised.

4a. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of proximity, should be supported.**

4b. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.**

4c. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of symmetry, should be supported.**

4d. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of good continuity, should be supported.**

4e. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.**

4f. **In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of inference of common fate, should be supported.**

5.5.3 Consistency with User's Stored Knowledge

As already noted, the design of the eNEWS chart was considered by nurses to be consistent with the design of the NEWS chart. In order to establish design principles for REVIEWS that are consistent with a user's stored knowledge of chart design it is worthwhile identifying the component parts of the NEWS chart design. Bertin, (1983), posits that in order to analyse information presented on a graphic display, there is a necessity to rigorously define the components of the information, *specifying their number, length and level*. Bertin classifies these as: *the invariant and the component, the number of components, the length of the components and the*

level of organization of the components. The following sections will describe each of these and establish how to apply the components to the design of the NEWS chart.

5.5.3.1 The Invariant and the Components

> *Information is a series of correspondences observed within a finite set of variational concepts of "components". All the correspondences must relate to an invariable common ground, which we will term the "invariant"*, (Bertin, 1983, pg. 16).

Bertin posits that it is necessary to define these terms in order to communicate complex information, to establish the optimal means of graphic representation for the information and to establish the wording for the chart's title and legend. An invariant refers to an unchanging value (Eysenck, 2004). The component/variant then relates to the variable recorded data. In order for the value of the variant to have a contextual meaning, there is a necessity for the invariant to also be presented. In the case of a vital sign presented on the NEWS chart, the vital sign (correspondence) has two variational components, the value of the vital sign recorded and the time of the observation. The NEWS chart presents the invariants, representing the vital sign value on the Y-axis and representing the date and time on the X-axis.

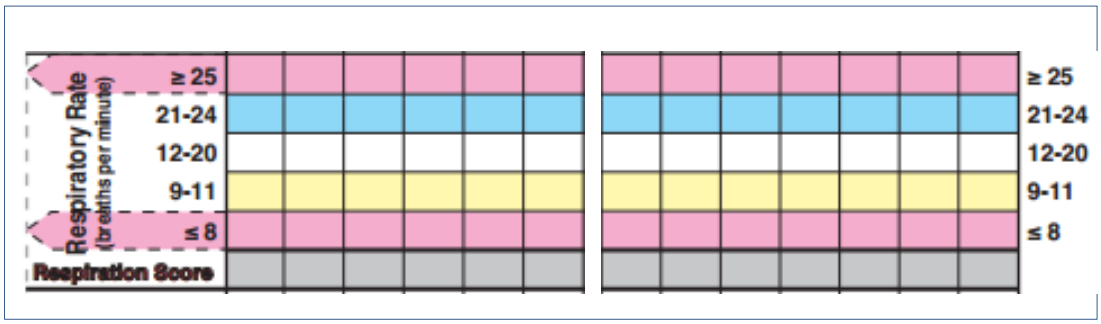


Figure 5.4. Extract from the paper-based NEWS chart.

Considering the information that needs to be recorded, the NEWS chart adequately labels the chart for variant and invariant information. While the eNEWS chart was deemed to have replicated the components, it was noted that the eNEWS chart did not have labels on the right hand side of the Y-axis. Considering the information presented in this section, the following design prescription can support consistency with user's stored knowledge:

5a. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each invariant in the chart.**

5.5.3.2 The Number of Components

While Bertin does not provide a definition for the number of components, the following are the consequences for this notion:

> *The number of visual variables necessary for the representation is at least equal to the number of components in the information.*
>
> *With three components, the information can be perceived as a single image. Beyond that, the perception of several successive images is often necessary.*
>
> *There are at least as many types of possible questions as there are components.*
>
> *The number of components is the best basis for classification of graphic construction,* (Bertin, 1983, pg. 28).

Considering the design of the NEWS and eNEWS charts, it can be observed that there are two components for each of the vital sign recordings. These are the value of the vital sign recorded, at a specific time. As such, the visual representation needs to represent these two components. Additionally, the NEWS charts currently records multiple individual vital signs (i.e. respiratory rate, SpO2, F1O2, Blood Pressure, etc.). There is also a need to present data for each of these on a separate plane. This is consistent with Preece et al.'s findings that each vital sign recording should be plotted separately. Individual vital signs are recorded on their respective areas with appropriate Y-axis invariant value ranges for each vital sign, with all vital signs sharing the date and time invariant data on the X-axis. This is appropriate as there is a necessity for each vital sign to have appropriate labels, furthermore vital signs are taken as a complete set, where all the vital signs are recorded collectively. Considering the information presented in this section, the following design prescription can support consistency with user's stored knowledge:

6a. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate the same number of components as the chart nurses are familiar with using.**

5.5.3.3 The Length of the Components

Bertin does not provide a definition of 'the length of the components', instead positing the following consequences of the rule:

> *"Long" (extensive) components lead to basic or "standard" constructions.*
>
> *"Short" (limited) components lead to "special" constructions.*
>
> *The visual variables utilised must have at least the same length as the components which they are meant to represent.*
>
> *In a problem involving more than three components, the minimum number of images necessary is a function of the length of the component,* (Bertin, 1983, pg. 33).

In the case of the NEWS and eNEWS chart, the individual planes present two components (i.e. the vital sign recording value, at a particular time). Bertin goes on to state that in cases where two or three components are being represented, there is a necessity to:

> *Utilise the two planar dimensions in homogenous, rectilinear and orthogonal manner.*
>
> *Employ an ordered retinal variable (size, value or texture) for representing the remaining component at the appropriate level of organisation.*
>
> *Order any reordarable component (by diagonalisation),* (Bertin, 1983, pg. 172).

A brief review of the NEWS and eNEWS charts establishes that the design of the charts meets the first rule. The charts use two planar dimensions for each vital sign, in an orthogonal manner (i.e. the X and Y-axis). However, it was noted from the evaluation of the eNEWS chart, that it did not maintain the second rule in respect to

employing retinal variables to represent components that are consistent with viewer's stored knowledge. During the evaluation of the eNEWS observation chart, nurses noted that they preferred to draw solid dots to represent all vital signs except for the blood pressure data points, where up and down arrows would be drawn. These retinal variables were not adequately represented in the eNEWS chart. Nurses also observed that the size of the chart was inconsistent with the paper-based NEWS chart. To maintain consistency with a user's stored knowledge, it is important to implement retinal variables that are consistent with their preferences. In order to understand how to consider the shapes from the perspective of the six ordered retinal variables, Table 5.6 presents definitions of the retinal variables as per Bertin, (1983).

Retinal Variable	Description
Size	Height of the column, area of a sign, number of equal signs.
Value	Various degrees between white and black.
Texture	With a variation in the fineness or coarseness of the constituents of an area having a given value. The variation can be obtained by enlarging or reducing a ruled photographic screen.
Colour	Using the repertoire of coloured sensations which can be produced at equal value.
Orientation	Various orientations of a line or pattern, ranging from the vertical to the horizontal in a distinct direction.
Shape	Since a mark with a constant size can nonetheless have an infinite number of different shapes.

Table 5.6. Six ordered retinal variables. Adapted from: (Bertin, 1983)

In the case of the eNEWS chart, while some nurses felt that it was the same as the paper-based NEWS chart, nurses noted the importance of the size, colour orientation and value and shape. In the case of size, nurses noted the size of the chart area as being different to the paper-based chart. While overall nurses preferred the smaller size of the chart, a number of nurses felt it would have a negative impact on the usefulness of the chart.

Nurses observed the usefulness of colour coding ranges where the value of the vital sign recorded corresponds to an individual EWS score. Nurses felt this design feature to be useful, however, they also noted that the electronically generated eNEWS chart has the potential for adding colour coding to the graph lines joining each data point and to colour code the aggregate NEWS score presented at the bottom of the chart. This is currently displayed on a grey background and nurses felt that appropriate colour coding of these scores could help alert them to an irregular NEWS score. In the case of orientation and value, nurses noted that the solid black lines joining data points on the eNEWS chart were more useful than the manually drawn lines between the data points on the paper-based NEWS chart.

It was observed that the eNEWS chart did not incorporate some of the important shapes that best practice required nurses to use when completing the paper-based NEWS chart. These were solid black dots to represent each data point and up and down arrows on the blood pressure recordings. Finally it can be observed that both the NEWS and eNEWS charts satisfy the third rule by ordering components by diagonalisation. Diagonalisation refers to connecting square matrices using a linear map, where square matrices represent a component (vital sign recording) and the linear map is a plot line used to connect the matrices. The use of the vital sign value and time invariant allow for the logical ordering of the components. Considering the information presented in this section, the following design prescriptions can support consistency with user's stored knowledge:

7a. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate two planar dimensions in homogenous, rectilinear and orthogonal manner.**

7b. **In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.**

7c. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.**

7d. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate lines to connect ordered data points.**

7e. **In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.**

5.5.3.4 Support for Analogical Reasoning

Bertin, (1983) posits that the previous three aspects of visual representation that support sense making have supported making it easier for an individual to acquire information explicitly displayed by a representation. Baker goes on to state that learning occurs as the viewer observes information that is present and that support of analogical reasoning can enable the user to discover information that remains hidden in the visual representation. The notion that information can remain hidden in a visual representation was repeated by nurses during evaluation of the NEWS and eNEWS charts. Nurses observed that comparing a patient's past records to their current records was useful in terms of allowing them to identify vital sign patterns for individual patients. For example, nurses noted that elderly patient's would typically present with low blood pressure in the morning after waking up or that a patient's blood pressure might rise after being visited by a Doctor on call.

While nurses felt that it was appropriate to compare an individual patient's vital signs to vital signs recorded during a previous stay, they felt it was inappropriate to use analogies to different patients. Nurses stated that as patient's had a large number of co-morbidities, it would be inappropriate to compare one patient to another. Upon reflection on Baker's definition of analogous thinking this observation is logical. Baker presents a position where comparing one situation to a situation with which the individual has stored knowledge can help them to understand a situation. The example of comparing the directional flow of electricity to the directional flow of water is given. In this case the analogy is appropriate as the conditions to explain each aspect of the directional flow of electricity are analogous to aspects which affect the flow of water. However, in a situation where every patient is different, it is difficult to employ this method.

As previously noted, during the evaluation of the NEWS and eNEWS charts, nurses noted the utility of being able to physically compare charts for individual patients, while this does not strictly meet Baker's definition of analogical reasoning, nurses felt that this was the only appropriate way to compare one situation to another. Considering this, the following design prescriptions can support analogical reasoning:

8a. **In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.**

5.5.4 The Framework for REVIEWS (Version 0.1)

The purpose of this chapter has been to leverages design knowledge formalised in phases 1 and 2 of this research project and to leverage extant literature to theorise about a design principles to improve the design of electronic observation charts. Section 5.5 has thus far theorised 23 principles that if instantiated can support aspects of visualisation that affect sense making and will therefore support information processing tasks performed by nurses when processing information presented on an observation chart. Table 5.7 presents the framework for REVIEWS V0.1 and the 23 design principles that constitute the framework.

The Framework for REVIEWS (V0.1)	
Support for the Four Basic Visual Perceptual Approaches	
	Association and Differentiation
1a	In order to facilitate initial interpretation of vital sign data, each vital sign should be assigned a proprietary plotting area.
	Ordered Perception
2a	In order to facilitate the user in perceiving the ordered value of data, the date and time of vital sign recordings should be incorporated in the visual representation.
2b	In order to facilitate the user in perceiving the ordinal value of vital sign data, colour coding should be applied to the vital sign ranges in which scores are associated with the vital sign recorded.

2c	In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.
2d	In order to facilitate the user in perceiving the ordinal value of vital sign data, preferential placement should be given to vital signs perceived by HCPs as being most important.
2e	In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.
	Quantitative Perception
3a	In order to facilitate the user in perceiving the ordinal value of vital sign data, vital sign values should be incorporated in the visual representation.
3b	In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.
3c	In order to facilitate the user in perceiving the quantitative value of data, a standardised approach to chart design should be employed.
	Support for Gestalt Grouping Qualities
4a	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of proximity, should be supported.
4b	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.
4c	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of symmetry, should be supported.
4d	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of good continuity, should be supported.
4e	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.
4f	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of inference of common fate, should be supported.

Consistency with User's Stored Knowledge	
	The Invariant and the Components
5a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.
	The Number of Components
6a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate the same number of variants.
	The Length of the Components
7a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate two planar dimensions in homogenous, rectilinear and orthogonal manner.
7b	In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.
7c	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.
7d	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate lines to connect ordered data points.
7e	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.
Support for Analogical Reasoning	
8a	In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.

Table 5.7. The Framework for REVIEWS (Version 0.1).

5.6 Conclusion

The purpose of this chapter was to identify the design knowledge necessary to develop the framework for REVIEWS V0.1, with the principle contribution of the chapter being the framework itself. As formalised in section 5.2, this research uses the phases of the updated Design Science Research Methodology (DSRM) process

model as presented in section 3.3.3.1. This chapter presented the initial design phases of DSRM process model. Section 5.3 presents the utility requirements for the design theory, that is to say the problem environment and the expected change the design theory is to affect. In this regard it was established that the problem environment can be defined as; *the initial assessment for acute illness*, *the continuous monitoring of patient's during their hospital stay* and *the early identification of potential clinical deterioration in patients*, with the objective of the design theory to improve how data is analysed and presented in order to *provide easier recognition of patient data* and to *aid identification of abnormal clinical parameters*.

In order to formalise knowledge that can guide the design of the framework (V0.1), there is then a necessity to synthesise kernel knowledge pertaining to the problem system. This kernel knowledge is presented in section 5.4. This section synthesized knowledge pertaining to the design of graphical interfaces and cognitive fit theory. From the cognitive fit literature, sense-making theory emerged as an appropriate lens for understanding how individuals interact with graphical interfaces when they are attempting to make sense of data presented on an interface. From this it was observed that the activities performed during sense-making are analogous to those performed during the information processing phase of the clinical reasoning process. As such, it was established that aspects of visual representation that affect sense-making would also likely affect information processing during clinical reasoning. A deeper exploration of literature pertaining to aspects of visual representation that affect sense making is then presented in section 5.4.

Having formalised the knowledge necessary to develop the design theory, section 5.5 presents an overview of how the design theory for this study was developed. The design theory in the case of this research is the framework for REVIEWS V0.1, which is a framework of individual design principles which are to be instantiated together. The individual design principles are developed by logically applying kernel knowledge to the design of a class of artefact (i.e. the electronic AWTTS chart). The result of this process was the development of 23 individual design principles which are designed to affect each of the aspects of visual representation that affect sense making.

Having formalised the knowledge necessary to create an instantiation of the design theory, chapter 6 presents the *demonstration* and the *evaluation* phases of the updated DSRM process model. The development of the instantiation phase will demonstrate how the V0.1 of the framework presented in this chapter can be practically instantiated in an electronic AWTTS chart. The utilitarian evaluation phase will demonstrate how useful the instantiated design framework is in terms of affecting the required change on the problem system.

Chapter 6 : INSTANTIATING AND EVALUATING THE FRAMEWORK FOR REVIEWS V0.1

6.1. Introduction

The purpose of this chapter is to present the *demonstration* and the *evaluation* phases for the design of the framework for REVIEWS V0.1. The purpose of the *demonstration* phase of the model is to demonstrate how a design theory or design principles can be practically instantiated in a class of artefact. Section 6.2 demonstrates how the design principles are applied to the design of the situated eNEWS chart (eNEWS V1.0). Section 6.3 presents the *evaluation* phase of the model, with the purpose of this phase being to demonstrate that the design principles instantiated in the artefact have had the required impact. In the case of the framework, the overall requirement for the utility is defined by the utility requirements (i.e. *to provide easier recognition of patient data, in order to aid identification of abnormal clinical parameters*). In order to achieve these requirements, the kernel knowledge presented in chapter 5 established that an observation chart should incorporate design features that afford the following visual representation qualities that impact sense making:

- Support for four basic visual perceptual approaches
- Support for Gestalt Qualities
- Consistency with user's stored knowledge and
- Support for analogical reasoning

In chapter 5, the design principles that constitute the framework for Retrospective Evaluation of Vital sign Information from Early Warnings Systems (REVIEWS) V0.1 were established. The required impact of these design principles is to positively affect the perceived utility of electronic observation charts in respect of the tasks performed by nurses when process processing information presented on the chart during the clinical reasoning process. Chapter 5 presented the initial three phases of the updated Design Science Research Methodology (DSRM) process model. The justification for choosing this approach is presented in chapter 3, with the phases of the approach described in section 3.3.3.1.

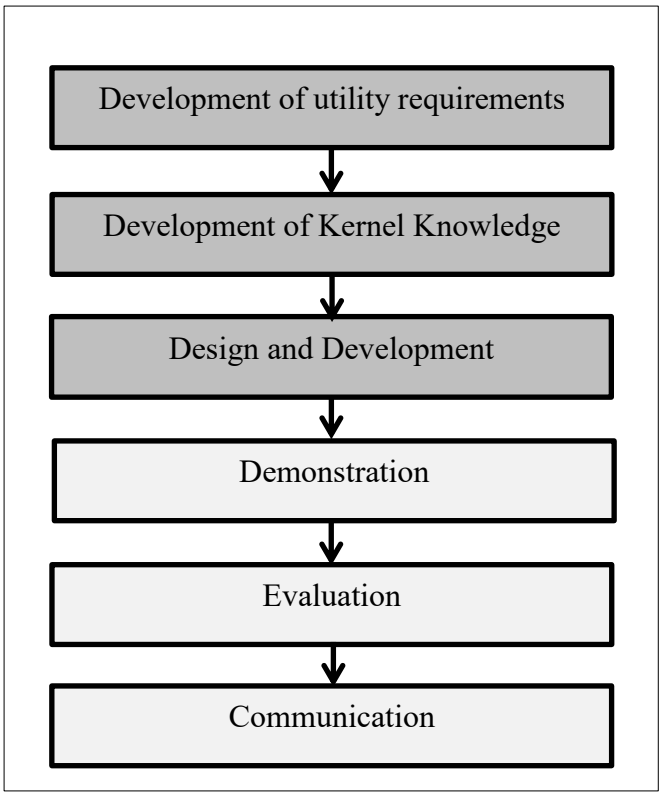


Figure 6.1. Updated DSRM phases highlighted in dark grey have been completed in chapter 5

6.2. Demonstration of the Framework for REVIEWS V0.1

The purpose of this section is to demonstrate how the design principles that constitute the framework for REVIEWS V0.1 can be instantiated. Section 6.1 observed that the framework was designed to be applicable to a class of artefact, i.e. electronic AWTTS observation charts. This research has previously evaluated an electronic observation chart, in the form of the eNEWS V1.0 chart (Section 4.3). Considering an evaluation of the utility of this chart has already been performed, this artefact presents a logical choice for instantiating the framework. Furthermore, as this chart was developed in-house, (by the Health Information Systems Research Centre) knowledge of the design of the application is available, as is resources for developing further iterations of the artefact. A key requirement of design science research is to demonstrate how design principles can be practically instantiated (Gleasure et al., 2012; Peffers et al., 2008), as such, the following sections will demonstrate the key considerations for instantiating the framework V0.1 on an existing application, these include evaluating the existing instantiation to establish

whether the design principles have already been adequately instantiated and the application of design principles which have not been instantiated.

6.2.1. Evaluating the eNEWS Chart for Instantiated Design Principles

The purpose of this section is to demonstrate how the framework for REVIEWS V0.1 can be practically instantiated as an iteration of a situated electronic AWTTS chart. Prior to instantiating the design principles that constitute the framework, there is a necessity to reflect on the design of the existing artefact to identify design principles that have already been adequately implemented in the design of the chart. This section will present the findings of this evaluation, which has been developed by considering the results of the evaluation of the eNEWS V1.0 chart performed in chapter 4 and comparing those findings to the design principles established in chapter 5. V0.1 of the framework consists of 23 design principles that afford the following visual representation qualities that impact sense making:

- Support for four basic visual perceptual approaches
- Support for Gestalt Qualities
- Consistency with user's stored knowledge and
- Support for analogical reasoning

These 4 aspects of visual representation will serve as the structure for the remainder of this section, with the following sections presenting the design principles associated with each visual representation quality and whether the design principles have been adequately instantiated in the eNEWS V1.0 chart.

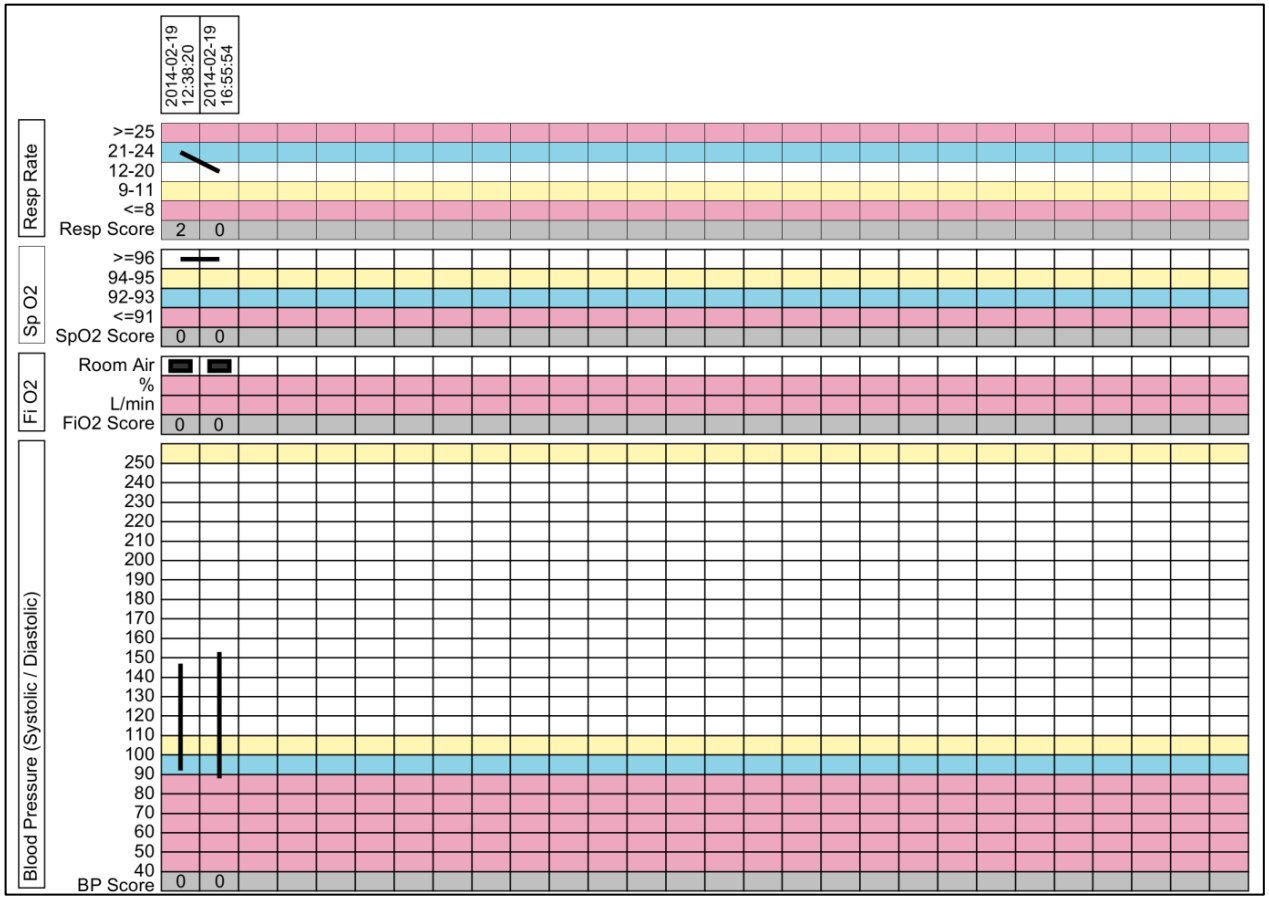


Figure 6.2. eNEWS V1.0 chart prior to instantiation of the framework for REVIEWS V0.1

6.2.1.1. Support for the Four Basic Visual Perceptual Approaches

The four basic visual perceptual approaches were described in chapter 5 as:

1. Association - *The viewer notes that two (or more) objects are similar, thus, can be grouped together*
2. Differentiation - *The viewer notes that two (or more) objects are different and must be placed in different groupings*
3. Ordered Perception - *The viewer notes that an object has more of a particular attribute than another item*
4. Quantitative Perception - *The viewer notes that an object has some multiple of an attribute possessed by another item*

From these visual perceptual approaches 9 individual design prescriptions were developed. These design prescriptions referred to grouping similar items together and differing items separately. In the case of AWTTS charts, research established that grouping individual vital signs separately was useful for facilitating this. **Design prescription 1a** states:

> *In order to facilitate initial interpretation of vital sign data, each vital sign should be assigned a proprietary plotting area.*

Considering that the eNEWS V1.0 chart allots a separated plotting area for each vital sign, it can be observed that the eNEWS V1.0 chart adequately instantiates design principle 1a.

The next design principles relate to supporting ordered perception, with section 5.2.4.1.2 defining ordered perception as when a viewer of data points notes that one object has more of a particular attribute than another. **Design prescription 2a** states:

> *In order to facilitate the user in perceiving the ordered value of data, the date and time of vital sign recordings should be incorporated in the visual representation.*

From a review of the eNEWS V1.0 chart it can be established that this design prescription is adequately met, as the time and date of each vital sign recording is displayed above the set of recordings.

Design principle 2b states:

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, colour coding should be applied to the vital sign ranges in which scores are associated with the vital sign recorded.*

From a review of the eNEWS V1.0 chart, this design prescription has been adequately instantiated, as colour coding is used for areas which correspond to an EWS score.

Design principle 2c states:

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.*

This design principle has not been adequately instantiated, as there is no key for assisting the user in understanding the colour coding schema.

Design principle 2d states:

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, preferential placement should be given to vital signs perceived by HCPs as being most important.*

Based on the evaluation of the NEWS and eNEWS V1.0 charts, this design principle has been adequately instantiated as nurses observed the fact that the vital sign that they considered to be most important is presented at the top of the chart.

Design principle 2e states:

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.*

From reviewing the eNEWS V1.0 chart, this design principle has not been adequately instantiated, as there is no label written above the data point representing the vital sign recorded.

Section 5.5.1.3 defines this task as; the viewer noting that an object has some multiple of an attribute possessed by another item. **Design principle 3a** states:

In order to facilitate the user in perceiving the ordinal value of vital sign data, vital sign values should be incorporated in the visual representation.

From a review of the eNEWS V1.0 chart, this design principle has been adequately instantiated with vital sign values presented on the left hand edge of the plot areas for each vital sign.

Design principle 3b states:

In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.

This design principle has not been instantiated in the eNEWS V1.0 chart, as the parameter values are only presented on the left hand edge of each vital sign plotting area.

Design principle 3c states:

In order to facilitate the user in perceiving the quantitative value of data, a standardised approach to chart design should be employed.

From a review of the eNEWS V1.0 charts this design principle has been adequately instantiated, as only one version of the eNEWS V1.0 chart is in use at a time, therefore ensuring that a standardised approach to chart design has been implemented. Table 6.1 presents the findings of this section.

Design Principle		Adequately Instantiated
1a	In order to facilitate initial interpretation of vital sign data, each vital sign should be assigned a proprietary plotting area.	**Yes**
2a	In order to facilitate the user in perceiving the ordered value of data, the date and time of vital sign recordings should be incorporated in the visual representation.	**Yes**
2b	In order to facilitate the user in perceiving the ordinal value of vital sign data, colour coding should be applied to the vital sign ranges in which scores are associated with the vital sign recorded.	**Yes**
2c	In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.	**No**
2d	In order to facilitate the user in perceiving the ordinal value of vital sign data, preferential placement should be given to vital signs perceived by HCPs as being most important.	**Yes**
2e	In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.	**No**
3a	In order to facilitate the user in perceiving the ordinal value of vital sign data, vital sign values should be incorporated in the visual representation.	**Yes**
3b	In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.	**No**
3c	In order to facilitate the user in perceiving the quantitative value of data, a standardised approach to chart design should be employed.	**Yes**

Table 6.1. Findings from analysis of eNEWS V1.0 chart from the perspective of support for the four basic visual perceptual approaches

6.2.1.2. Support for Gestalt Grouping Qualities

Gestalt grouping qualities were identified as being useful for supporting the determination of equality of intervals or differences or the identification of patterns. Section 5.4.3.2 defined these qualities as:

1. **Similarity** — *Units that are homogenous in colour and texture* (Spelke, 1990), *similar elements tend to be grouped together* (Fekete et al., 1973)

2. **Proximity** — *'Nearness' or 'adjacency' in the visual field* (Brunswik & Kamiya, 1953), *things that are close together are perceptually grouped together* (Fekete et al., 1973)

3. **Symmetry** — *Symmetrical visual patterns* (Bornstein et al., 1981), *two symmetrically arranged visual elements are more likely to be perceived as a whole* (Fekete et al., 1973)

4. **(Near) continuity** — *Smoothly contoured* (Spelke, 1990), *visual elements that are smoothly connected or continuous tend to be grouped together* (Fekete et al., 1973)

5. **Closure,** — *A closed contour tends to be seen as an object* (Fekete et al., 1973)

6. **An inference of common fate** — *Uniformity in motion* (Spelke, 1990)

Of these qualities, 6 design principles were identified which support the visual grouping of individual data points, therefore logically allowing an individual to perceive a relationship between the objects presented on a chart. **Design principle 4a**, states:

In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of proximity, should be supported.

From a review of the evaluation of the eNEWS chart, it is possible to establish that this design principle has been instantiated in the eNEWS V1.0 chart. As vital sign data points are plotted from left to right on their respective plotting areas, the Gestalt grouping quality of proximity is instantiated.

Design principle 4b, states:

In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.

The grouping quality of similarity has also been observed in the design of the eNEWS V1.0 chart. This is instantiated in how all related vital sign data points are represented in the same way. For example, blood pressure is represented with a vertical line linking the systolic and diastolic blood pressure readings, AVPU and Fi O2 recordings are represented using solid black rectangles and all other data points are represented using a continuous black line.

Design principle 4c, states:

In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of symmetry, should be supported.

While the law of symmetry will not apply to the individual data points plotted on a graph area, the law of symmetry is observed in the design of the plotting area. The plotting area takes the form of a symmetrical rectangle, in which the data points are plotted. This allows the object to be perceived as a whole as the symmetrical plot area is visually separate from other proprietary plotting areas.

Design principle 4d, states:

In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of good continuity, should be supported.

The Gestalt grouping law of good continuity is observed in the design of the eNEWS V1.0 chart, through the use of a solid black line to link vital sign data points.

Design principle 4e, states:

> *In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.*

In the case of the eNEWS chart, the Gestalt grouping quality of closure has not been adequately instantiated. While the evaluation of the eNEWS V1.0 chart demonstrated that nurses could perceive when objects closed, it was observed that they would require arrows at the top and bottom of the blood pressure readings and black dots at each vital sign recorded. Nurses observed that they would have less trust in the legitimacy of recordings that would not use these techniques for closing the objects.

Design principle 4f, states:

> *In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of inference of common fate should be supported.*

The Gestalt grouping quality of common fate, states that if an object appears to be moving in the same direction it will be grouped together. This quality is instantiated in the eNEWS V1.0 chart, as it can be observed that all vital sign data points are recorded from left to right with a single black line connecting all the data points. These qualities give the appearance that the data points are moving in the same direction. Table 6.2 presents a review of the findings from this section.

Design Principles		Adequately Instantiated
4a	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of proximity, should be supported.	**Yes**
4b	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.	**Yes**
4c	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of symmetry, should be supported.	**Yes**
4d	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of good continuity, should be supported.	**Yes**
4e	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.	**No**
4f	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of inference of common fate, should be supported.	**Yes**

Table 6.2. Findings from analysis of eNEWS V1.0 chart from the perspective of support for Gestalt grouping qualities

6.2.1.3. Consistency with User's Stored Knowledge

Representing data in a manner which is consistent with the user's stored knowledge can reduce the cognitive cost of processing the data representation on a visualisation. Hutchins et al., (1985), described this as reducing the gulf between the user's knowledge and that of the interface designer. As the health professionals interviewed for the research were most familiar with the paper-based NEWS chart, this chart will serve as the reference for the user's stored knowledge. In order to identify the components of an information representation that can be consistent with a user's stored knowledge, section 5.5.3 decomposed a visual representation into the following characteristics:

I. The Invariant and the Components

> *Information is a series of correspondences observed within a finite set of variational concepts of "components". All the correspondences must relate to an invariable common ground, which we will term the "invariant".*

The invariant and the components are described in further detail in section 5.5.3.1, with **design prescription 5a,** stating:

> *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.*

In the case of the eNEWS V1.0 chart, the components of the invariant were identified as:

1. Value of the vital sign recorded, at
2. A specific Date and Time

While the eNEWS chart did have labels for the value of the vital signs recorded on the left hand edge of the plotting area and a specific time and date for each recording set at the top of the chart, it did not present labels for each vital sign recorded. It was observed during evaluation of the paper-based NEWS chart that the nurses preferred charts where the nurse had written down the value of the vital sign recorded above each data point in the plotting area. As such, it can be observed that while eNEWS V1.0 chart does incorporate some of the appropriate labels for each variant in the chart, it does not comprehensively or adequately do so.

Design Principle		Adequately Instantiated
5a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.	**No**

Table 6.3. Findings from analysis of eNEWS V1.0 chart from the perspective of the invariant and the components.

II. The Number of Components

The number of visual variables necessary for the representation is at least equal to the number of components in the information.

With three components, the information can be perceived as a single image. Beyond that, the perception of several successive images is often necessary.

There are at least as many types of possible questions as there are components.

The number of components is the best basis for classification of graphic construction.

In the case of the eNEWS chart, there are 2 variants for which data needs to be represented.

Design principle 6a, states:

In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate the same number of variants.

Considering the design of the NEWS and eNEWS charts, it can be observed that there are 2 variants for which data needs to be represented. These are: 1) the value of the vital sign recorded, 2) at a specific time and date. As such, the visual representation needs to represent these three variants. Further to this, the NEWS charts currently records multiple individual vital signs (i.e. respiratory rate, SpO2, F1O2, Blood Pressure, etc.), there is also a need to present data for each of these on a separate plane. The values of the vital signs are represented on the X-axis. This is consistent with Preece et al.'s findings that each vital sign recording should be plotted separately. Individual vital signs are recorded on their respective areas with appropriate Y-axis value ranges for each vital sign, with all vital signs sharing the date and time. This is appropriate as there is a necessity for each vital sign to have appropriate labels, furthermore vital signs are taken as a complete set, where all the vital signs are recorded together. As such, it can be stated that the eNEWS chart adequately instantiates design principle 6a.

Design Principle		Adequately Instantiated
6a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate the same number of variants.	**Yes**

Table 6.4. Findings from analysis of eNEWS V1.0 chart from the perspective of the number of components

III. The Length of the Components

> *"Long" (extensive) components lead to basic or "standard" constructions.*
>
> *"Short" (limited) components lead to "special" constructions.*
>
> *The visual variables utilised must have at least the same length as the components which they are meant to represent.*
>
> *In a problem involving more than three components, the minimum number of images necessary is a function of the length of the components*

There are two components which need to be represented for each of the vital signs recorded on the eNEWS V1.0 chart, as such, the method of using an X and Y-axis to plot the vital sign data points is appropriate. **Design principle 7a**, states:

> *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate two planar dimensions in homogenous, rectilinear and orthogonal manner.*

As the eNEWS chart uses a plotted graph with an X and Y-axis design, the eNEWS chart adequately instantiates design principles 7a.

Further to this, it was established that when designing a graph that is consistent with a user's stored knowledge it must be consistent with the ordered retinal variables. The following design principles are based on these retinal variables, with **design principle 7b**, stating:

In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.

Evaluation of the eNEWS V1.0 chart demonstrates that the plotting area of the eNEWS chart in comparison to the paper-based NEWS chart shows that the size of the eNEWS chart was perceived to be smaller than the NEWS chart, with some nurses considering the smaller size to be useful, while other nurses found that the smaller size was difficult to read. A physical comparison of the two charts demonstrates that the eNEWS V1.0 chart uses matrix rectangles that are measured 6 mm wide by 4 mm high, with the paper-based NEWS chart using matrix rectangles that are 7 mm wide by 5 mm high. This gives the eNEWS V1.0 matrices a total area of 24 mm and the NEWS matrices of 35 mm, an area differential of 31%. While some nurses observed the usefulness of the smaller, "neater" chart, in order to maintain a chart that is at least as useful, the area of the matrices used should be more similarly sized. As such, it can be stated that the eNEWS chart does not adequately instantiate design principle 7b.

Design principle 7c, states:

In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.

A review of the eNEWS V1.0 chart demonstrates that it maintains consistency with the NEWS chart in terms of the use of colour coding for colour coding plot areas which relate the EWS scores. It was noted by nurses that the electronically generated observation charts have the potential for further use of colour coding for the area where the individual EWS scores and the aggregate NEWS scores are presented. These area currently employ a grey background, nurses observed that these areas would be more useful if they were also colour coded. As such, it can be observed that the eNEWS chart currently observed design principle 7c, however, there is the potential for the eNEWS chart to make further use of this design principle.

Design principle 7d, states:

In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate lines to connect ordered data points.

This rule is built on the design principles observed in section 6.2.1.2, however, while the Gestalt grouping qualities suggested the use of continuous lines might be appropriate, this rule explicitly states that a continuous line should be used. When using the paper-based NEWS chart, the best practice is to use solid lines to connect the vital sign data points. In order to maintain a consistency with the user's stored knowledge, electronic observation charts should employ design principle 7d. The eNEWS chart uses a solid black line to connect vital sign data points and it can be observed that the eNEWS chart sufficiently instantiates this design principle.

Design principle 7e, states:

In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.

From evaluation of the paper-based NEWS chart it was established that the best practice for use of the eNEWS V1.0 chart was to use solid black dots to represent all data points on graphed sections, with up and down arrows to be used on the blood pressure representations. The use of shapes was observed in design principle 4e, which supports the Gestalt grouping quality of closure. However, design principle 7e establishes that the shapes that are used should be consistent with those that the user is already familiar with. As the eNEWS V1.0 chart does not use shapes that were observed as best practice on the paper-based NEWS chart, it can be observed that the eNEWS V1.0 chart does not sufficiently instantiate design principle 7e. Table 6.5 presents the findings from this section.

Design Principle		Adequately Instantiated
7a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate two planar dimensions in homogenous, rectilinear and orthogonal manner.	**Yes**
7b	In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.	**No**
7c	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.	**Yes**
7d	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate lines to connect ordered data points.	**Yes**
7e	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.	**No**

Table 6.5. Findings from analysis of eNEWS V1.0 chart from the perspective of the length of the components.

6.2.1.4. Support for Analogical Reasoning

Section 5.5.3.4 describes the reasoning for the final design principle of the framework for REVIEWS V0.1. This design principle is concerned with allowing an individual nurse to be able to compare patient records, with design **principle 8a**, stating:

> *In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.*

In the case of the eNEWS V1.0 chart this design principle has been instantiated. The eNEWS system allows for individual patient charts to be printed through a

networked printer on request. These physical instantiations of the eNEWS V1.0 chart can then be physically compared by the user.

Design Principle		Adequately Instantiated
8a	In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.	**Yes**

Table 6.6. Findings from analysis of eNEWS V1.0 chart from the perspective of support for analogical reasoning

6.2.2. Applying the Framework for REVIEWS V0.1 to the eNEWS Application

Section 6.2.1 identified which of the design principles that constitute the framework for REVIEWS V0.1 have already been adequately instantiated in the eNEWS V1.0 chart; the purpose of this section is now to present the practical instantiation of the design principles which have not been adequately instantiated. This is a necessary step to complete prior to evaluation of the eNEWS V2.0 chart, as without demonstrating that the framework can be practically instantiated, it is difficult to perform a utilitarian evaluation of the framework. Table 6.7 presents the design principles which have not been adequately instantiated in the eNEWS chart.

Design Principle	
2c	In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.
2e	In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.
3b	In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.
4e	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.
5a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.
7b	In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.
7e	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.

Table 6.7. Framework for REVIEWS V0.1 Design Principles not instantiated in eNEWS chart.

Having presented the design principles which have not been instantiated in the eNEWS chart, this section will present how these design principles have been instantiated in version 2.0 of the eNEWS chart.

6.2.2.1. Design Principle 2c

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented*

Design principle 2c is concerned with facilitating ordered perception and posits that instructions for understanding the colour coding system on the eNEWS chart should be presented. This finding is consistent with the evaluation of the eNEWS chart, where nurses observed that it might be difficult for nurses who are not experienced

using the chart to interpret the meaning of the colour coding system. Furthermore, this design principle has been instantiated on the paper-based NEWS chart and as such, it should also be present on the NEWS chart.

6.2.2.2. Design Principle 2e and 5a

> *In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.*
>
> *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.*

It can be observed that there is a logical link between design principle 2e and 5a, while design principle 2e suggests that a label should be displayed directly above the vital sign data point in the plotted area, design principle 5a suggests that appropriate labels should be printed for each variant in the chart. In the case of the eNEWS chart, the only variant that a label has not been printed for is the vital sign data point.

By presenting the figure directly above the data point, this will minimise the time spent by users comparing the data point to the Y-axis label which presents the vital sign ranges. Furthermore, by presenting the vital sign recorded it allows the nurse reading the chart to get a more accurate picture of the patient's health.

6.2.2.3. Design Principle 3b

> *In order to facilitate the user in perceiving the quantitative value of data, parameter values should be written on both sides of the chart*

Section 6.2.1.1, observed that at the moment the parameter values are only presented on the left hand edge of the eNEWS chart. V2.0 of the eNEWS chart will also display the parameter values on the right side edge of the chart.

6.2.2.4. Design Principle 4e and 7e

> *In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.*

In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.

In the case of the eNEWS V1.0 chart, closure is not adequately supported as while a user can perceive a continuous line to be ended, nurses observed that they would not have full confidence in a continuous line that did not use shapes to close the object. As such, it is important to incorporate shapes that are consistent with the user's stored knowledge to close objects. In the case of the paper-based NEWS chart, solid black dots are used to represent each data point on the plotting area for individual vital signs, with up and down arrows used to represent systolic and diastolic blood pressure readings respectively.

6.2.2.5. Design Principle 7b

In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.

Section 6.2.1.3 established that the eNEWS chart presented matrices for plotting vital sign data points that are 31% smaller than those presented on the paper-based NEWS chart. While it is difficult to establish an optimal matrix size without comparing multiple matrix sizes, it would be appropriate to increase the size of the matrices so they are as close to the size of the paper-based NEWS chart matrices as possible.

6.2.3. Instantiating the Framework for REVIEWS V0.1

Section 6.2.2 presents the prescriptions for design features that were to be instantiated in the eNEWS V2.0 chart. Dr Simon Woodworth, the software developer for the eNEWS project was then asked to instantiate the requested design features. Figure 6.3 represents an extract from the final version of the eNEWS V2.0 chart with the instantiated design features.

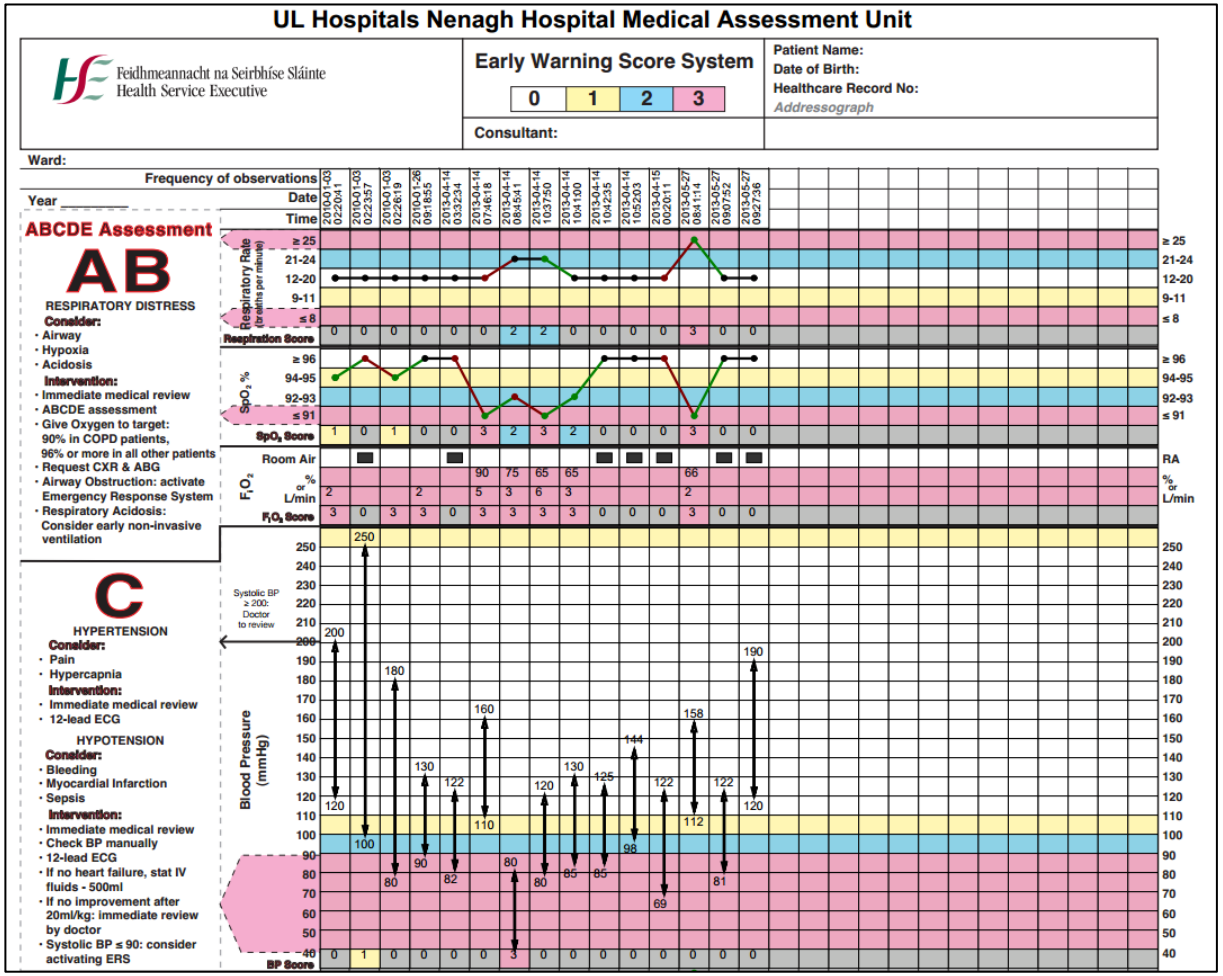


Figure 6.3. Extract from the eNEWS V2.0 chart.

Section 6.2.1 presents analysis of the eNEWS V1.0 chart from the perspective of the framework for REVIEWS V0.1. Based on this analysis, a number of design prescriptions were identified which were not already adequately instantiated in the chart. Based on these design prescriptions a number of new design features were instantiated in the eNEWS V2.0 chart. These design features are presented in Table 6.8.

Further to the design features that were identified as not being adequately instantiated on the eNEWS V1.0 chart, two experimental design features were developed based on the design principles that constitute the framework. These design features were designed based on feedback given by nurses during the comparative evaluation of the NEWS and eNEWS V1.0 charts and correspond to design principles **4b** and **7c.**

- **4b** *In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.*
- **7c** *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.*

Furthermore, these design features take advantage of the computerised nature of the eNEWS system, where data collected through the interface can be dynamically analysed and the data can then be presented in a manner which gives context to the data. These design features are also presented in Table 6.8.

Design Principle		Instantiation in eNEWS V2.0
2c	*In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.*	Standard format for instructions for understanding NEWS scores from HSE's paper-based NEWS chart used presents on chart.
2e **5a**	*In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.* *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.*	Labels for systolic and diastolic blood pressure are presented above and below the graph. It was the position of the developer that adding labels to all data points would clutter the interface.
3b	*In order to facilitate the user in perceiving the quantitative value of data, parameter values should be written on both sides of the chart.*	Parameter values are added to the right hand edge of the chart area.
4e **7e**	*In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.* *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.*	Black dots are added to data points where vital signs are graphed. Up and down arrows are added for diastolic and systolic blood pressure.

Design Principle		Instantiation in eNEWS V2.0
7b	*In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.*	Chart is designed using vector graphics, so chart can be printed at A3 size without distorting the clarity of the graphic.
4b	*In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.*	Area for presenting individual and aggregate weighted vital sign scores are colour coded based on the calculated score.
7c	*In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.*	Vital sign graph lines are dynamically coloured. *Red* indicates a rise in EWS score, *Green* indicates a decrease and Black indicates no change.

Table 6.8. Instantiations of design principles from framework for REVIEWS V0.1 in eNEWS V2.0 chart

6.3. Evaluating the Utility of the Framework for REVIEWS V0.1

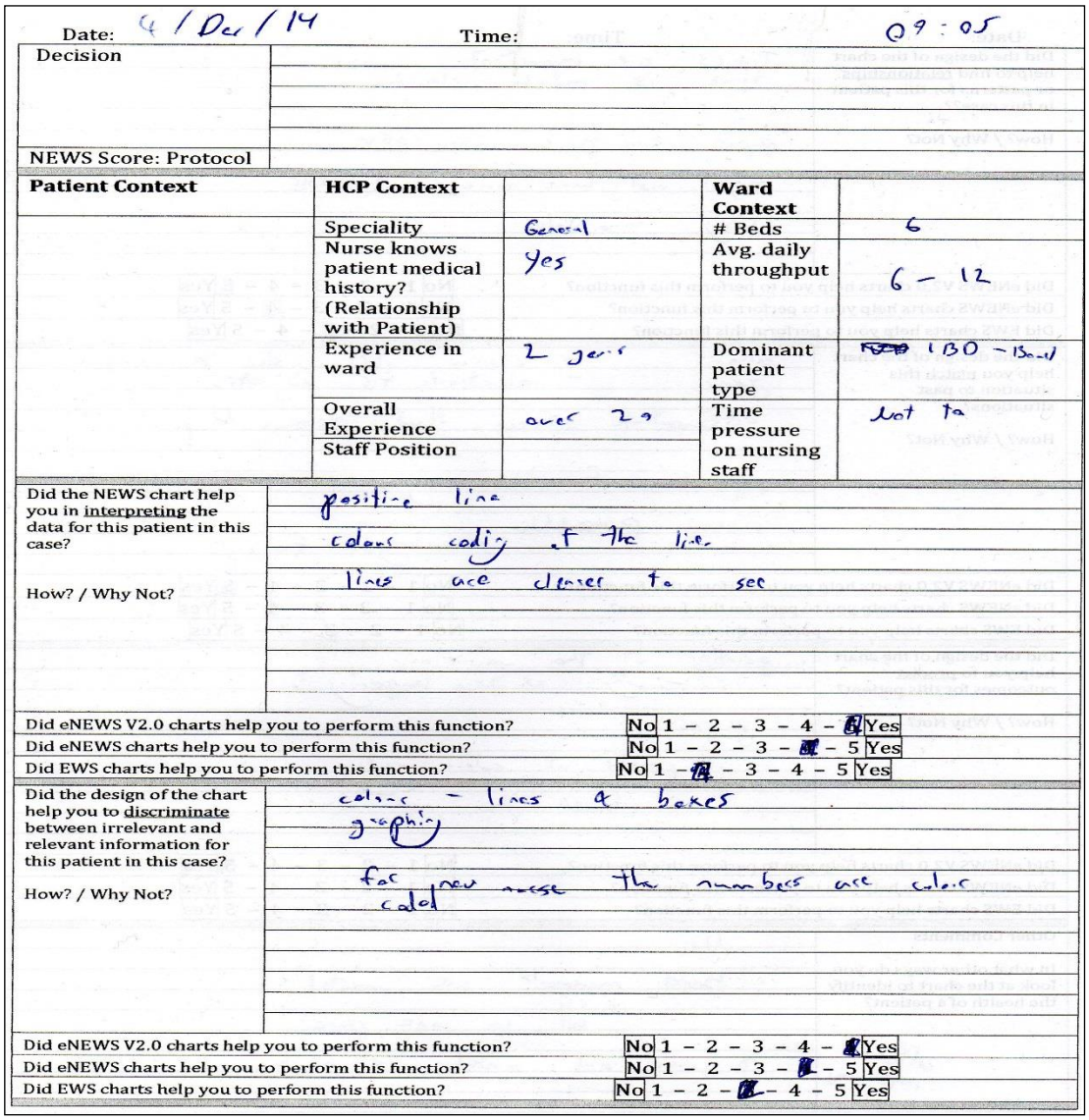
In order to establish the utility of the framework for REVIEWS V0.1, there is a necessity to compare the artefact to other situated artefacts. Chapter 4 presented comparative evaluations of both the HSE's paper-based NEWS chart and the Science Foundation Ireland (SFI) funded, electronically-generated eNEWS chart developed by the HISRC in UCC. These evaluations established that the paper-based NEWS chart was found to be more useful than legacy charts previously used by nurses and the electronically-generated eNEWS chart was found to be at least as useful as the paper-based NEWS chart. These two evaluations employed semi-structured interviews with nurses who have previous experience of using the paper-based NEWS chart. Having established the means by which the framework has been instantiated in eNEWS V2.0 in section 6.2.3, the following sections will present how the eNEWS V2.0 chart will be comparatively evaluated in relation to eNEWS chart V1.0 and the paper-based NEWS chart.

6.3.1. Method

In chapter 4 a semi-structured interview method was presented to perform the comparative evaluation of the paper-based NEWS chart compared to legacy observation charts that interviewees had experience of using and the comparative evaluation of the paper-based NEWS chart compared to the electronically generated eNEWS V1.0 chart. The principles for selecting this approach are presented in section 3.6.2, with the semi-structured approach being chosen to allow for interview subjects to provide richer feedback on the interview questions. For each comparative evaluation phase an interview guide is prepared which focuses on collecting data that establishes the perceived utility of the artefact in terms of supporting each task of the information processing phase of the clinical reasoning process.

This chapter presents the comparative evaluation of the paper-based NEWS chart, V1.0 of the eNEWS chart and V2.0 of the eNEWS chart which represents an instantiation of the framework for REVIEWS V0.1. 9 nurses were interviewed with an average of over 20 years of experience who were all familiar with the use of the paper-based NEWS chart were interviewed. The interviews were recorded using a voice recorder and an interview guide to capture contextual information that would otherwise be missed when using a voice recording as the main data source. The

interview guide used in chapter 3 has been adapted to include 5 item Likert scales to allow the subjects to comparatively rate the eNEWS V2.0 chart, the eNEWS V1.0 chart and the paper-based NEWS chart in terms of how well its design features support the information processing tasks. In relation to the Likert scales, a score of '1' corresponds to the chart not helping at all, while a score of '5' corresponds to the chart being perceived as very helpful. Figure 6.4 presents an extract from the interview guide (See Appendix 7 for interview guide script).



Date: 4 / Dec / 14 Time: 09:05

Decision				
NEWS Score: Protocol				
Patient Context	**HCP Context**		**Ward Context**	
	Speciality	General	# Beds	6
	Nurse knows patient medical history? (Relationship with Patient)	Yes	Avg. daily throughput	6 – 12
	Experience in ward	2 years	Dominant patient type	130 – 150
	Overall Experience	over 2 y	Time pressure on nursing staff	Not to
	Staff Position			

Did the NEWS chart help you in interpreting the data for this patient in this case?

How? / Why Not?

positive line
colors coding of the line.
lines are closer to see

Did eNEWS V2.0 charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes
Did eNEWS charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes

Did the design of the chart help you to discriminate between irrelevant and relevant information for this patient in this case?

How? / Why Not?

colors – lines & boxes
graphic
for color new news the numbers are color

Did eNEWS V2.0 charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes
Did eNEWS charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function? No 1 – 2 – 3 – 4 – 5 Yes

Figure 6.4. Extract from interview guide

Once interviews were completed, the same method of inductive qualitative data analysis was employed as presented in chapters 3 and 4. The steps of this process are presented in Table 6.9.

Phase	Description
1. Preparation of raw data files (Data cleaning).	Format the raw data files in a common format if required. Make a backup of each raw data file.
2. Close reading of text.	Read raw text in detail to become familiar with the text and gain an understanding of emerging themes from the interviews.
3. Creation of categories.	Define categories or themes. Upper categories defined by research objectives, lower level categories defined by emerging themes. Create Concept Centric Matrix (CCM) based on these themes.
4. Overlapping coding and uncoded text.	Identify areas of text where multiple themes have emerged. Identify text where no themes have emerged. Summarise the findings using a CCM.
5. Continuing revision and refinement of category system.	Search for subtopics such as contradictory points of view and new insights. Select appropriate quotes that convey these emerging messages.

Table 6.9. A general inductive approach for qualitative data analysis. (David R. Thomas, 2003)

6.3.2. Results – Data Display

The purpose of this section is to compress the major findings from the data analysis in a clear and adequately comprehensive manner. The approach for presenting the analysis will be the same as that presented in chapter 3 for the evaluation of the NEWS and eNEWS charts. That is to say, the data display will take the form of a narrative text with analysis of the extracts from the CCM and the Likert scales used to summarise the findings and indicate the performance of the eNEWS V2.0 chart compared to the legacy charts. This approach is consistent with the approach employed by Appleton, (1995) who developed this approach to ensure that qualitative research was analysed and presented in a valid and reliable manner.

6.3.3. Overview – A Significant Positive Impact from the Framework for REVIEWS V0.1

The dominant theme that emerged from the analysis of the interviews was that the eNEWS V2.0 chart was considered to be more useful than both the paper-based NEWS chart and the eNEWS V1.0 chart. An analysis of the results of the Likert

scales for each interview question demonstrates this, with the eNEWS V2.0, eNEWS V1.0 and the paper-based NEWS chart receiving an average score of 4.37, 2.86 and 3.2 respectively based on the five constructs being measured. These findings are initially indicative that applying the framework for REVIEWS V0.1 to the design of the eNEWS V1.0 chart had the desired impact, with *nurse 4* stating:

> *Yeah, well this one definitely is better, definitely, definitely, definitely better. It's very good.*

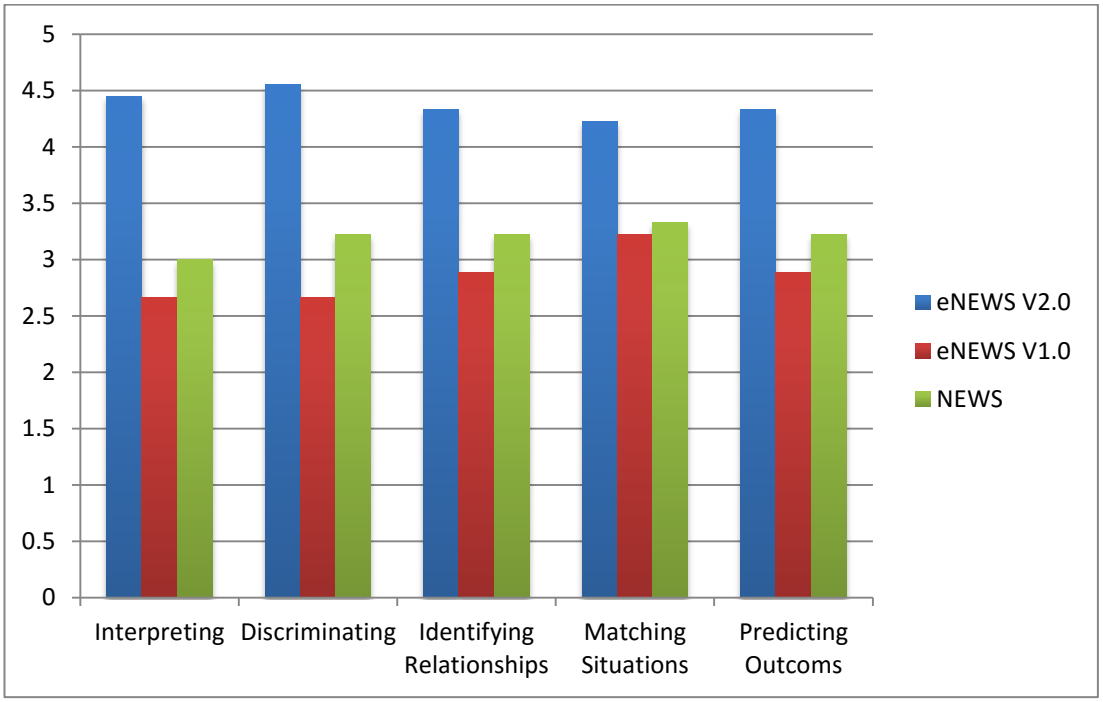


Figure 6.5. Summary of analysis of Likert scales for comparison of eNEWS V2.0, eNEWS and NEWS charts.

Considering the results presented in Figure 6.5 in the context of the findings of the comparative evaluation of the eNEWS and NEWS charts presented in chapter 4 is useful for helping to explain the context of these findings. In the initial evaluation of the eNEWS V1.0, it was established that the chart was considered to be at least as useful as NEWS, whereas in the evaluation of the eNEWS V2.0 it was established that in all cases the NEWS chart was considered to be more useful than the eNEWS chart. This is likely due to the relative focus of each evaluation phase. In each evaluation phase the focus was placed on the newest chart iteration. In the case of the initial evaluation, the focus was on the eNEWS V1.0 chart and the interviewees were able to spend more time analysing the chart and establishing the usefulness of the

chart. In the case of this evaluation, many of the nurses felt that it was initially inferior to the NEWS chart, however, as they considered each task that they perform when using the charts, they were able to identify a number of design features that were superior to the paper-based NEWS chart. These design features are presented in section 4.3.4.3 and include: bold black graph lines, standardisation of presentation of data and presentation of more accurate data.

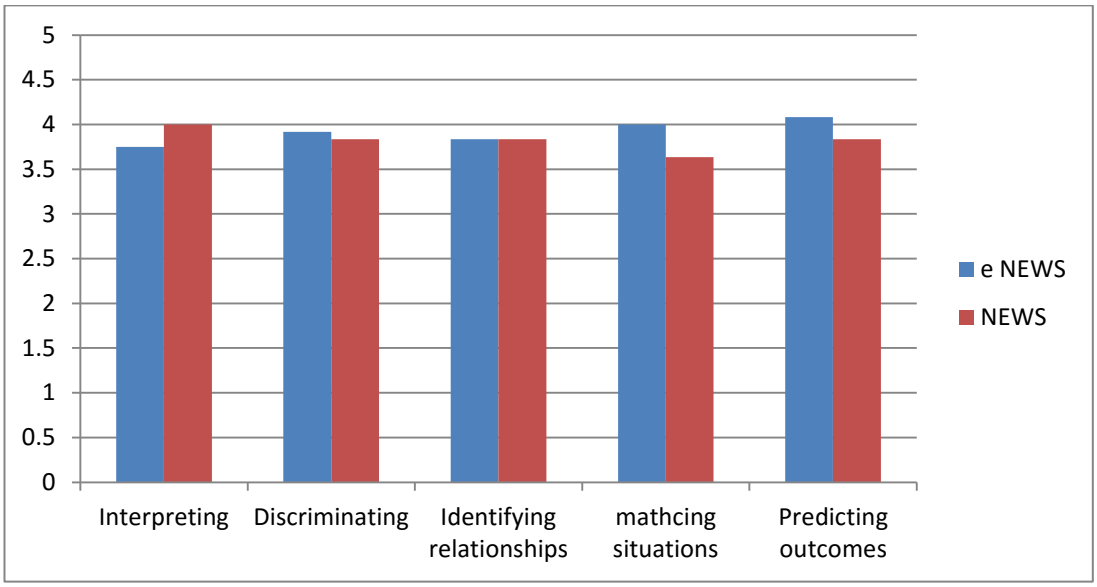


Figure 6.6. Summary of analysis of Likert scales from comparative evaluation of eNEWS V1.0 and NEWS charts.

In the case of the more recent evaluation where eNEWS V2.0 was introduced to the comparative evaluation all of these design features were maintained, however, a number of novel design features were also instantiated. Design principles **7b** and **7e** in particular introduce design principles that suggest that the design of the chart should introduce elements that are consistent with the user's stored knowledge. These design principles were introduced to ensure that new design features instantiated on the chart are consistent with design features the nurses already use. As such, when viewing the charts the nurses observed fewer differences between the paper-based NEWS chart and the electronically generated eNEWS chart. This is likely to have introduced some status-quo bias (Kim, 2009). That is to say; the usefulness of the visually different chart is discounted when a chart that is visually similar to the paper-based chart is introduced. This observation is also important as the perceived impact of a number of the design principles implement in the eNEWS V2.0 chart are affected by the design principles **7b** and **7e**. Considering the results of

the evaluation of eNEWS V1.0, we can observe that when the eNEWS V2.0 chart is not presented, nurses are more inclined to adapt to the different format, with one nurse stating:

> *Well that eNEWS chart is very easy to understand. Sure once you're used to using that then they are pretty much the same.*

The initial findings that the eNEWS V2.0 chart is considered to be more useful for each task performed by nurses when making sense of data presented on an AWTTS observation chart is desirable with regard to the overall objective of this research effort. However, there is still a requirement for this research to be able to demonstrate a correlation between the impact of specific design principles established in chapter 4 and the outcomes of the interviews. This analysis is presented in greater detail in section 6.3.4.

Design principle **7b** (i.e. *In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with*) was specifically mentioned during interviews as being helpful. This design principle was designed to support analogical reasoning (i.e. matching). The paper-based NEWS chart is printed on a standard A3 sized page, with the eNEWS V1.0 chart being printed on a standard A4 sized page. During the interviews performed for the comparative evaluation of the eNEWS V1.0 and NEWS charts, the size of the electronically generated chart was mentioned by a number of nurses as being a negative design element, with other nurses preferring the smaller size. In order to maintain consistency with the user's stored knowledge it was decided that the eNEWS V2.0 chart should be printed on an A3 sized page. In this case one nurse observed that the larger size was of benefit to them when matching situations, with the nurse stating:

> *The bigger size is definitely needed, because is just too much information squeezed into a smaller version.*

The two experimental design features that were instantiated in the eNEWS chart were also identified as having a positive impact on nurse's ability to process information presented on the observation chart. Colour coding the area in which the early warning score is presented was identified by 3 nurses as being useful for

helping to interpret vital sign information, with 5 nurses observing that it was useful for helping them to discriminate between more and less important information. The following extract from an interview with a nurse is indicative of the general feedback on this design feature:

> ***Interviewer****: Would you say the colour coding is improved compared to that (original) or is it something different?*
>
> ***Nurse****: It looks different colour coding really, but it isn't, it's the same.*
>
> ***Interviewer****: So what you are pointing at there is the fact that the boxes are colour coded.*
>
> ***Nurse****: Yeah, you see if you were coming in as a new nurse to this patient, obviously you have a nice base line here to go by.*
>
> ***Interviewer****: So it's not just the fact that the numbers are there, but the fact that the numbers are colour coded?*
>
> ***Nurse****: Yeah, because it does make it clearer, whereas here it is all numbers black on grey, it is clearer, obviously red is most important.*

The second experimental design feature was found to have had less of an impact on the usefulness of the eNEWS V2.0 chart. Colour coding the graph line to indicate an improvement or dis-improvement in the patient's vital signs was identified 1 time for facilitating interpreting information, 1 time for facilitating discriminating data and 1 time for helping to make predictions for patient outcomes. The low impact of this design feature is likely due to the novelty of the design feature. While previous design features were easy for nurses to identify, many nurses did not notice the fact that the graph lines were colour coded. It is likely that if the purpose of colour coding the graph lines had been explained to nurses, then more nurses would have identified the design feature as being useful. The following extract demonstrates how nurses did not understand the purpose of the design feature without it being explained to them.

> ***Nurse:*** *Yeah the colour coding I suppose, the green and red if they program would do it itself, that's something I would probably get*

used to, not having seen it before, I understand what you are trying to do, having a green going up and a red coming down.

Interviewer: *Yeah, but maybe as it is the colours aren't bright enough?*

Nurse: *No its fine brightness wise, I just didn't understand it initially and now that I understand it, I like that aspect of it.*

This finding is consistent with design principle 2c that notes the importance of including instructions for understanding a colour coding system to facilitate the user in perceiving the ordered value of data.

6.3.4. Specific Design Features Identified as Having a Positive Impact on Usefulness

This section presents an analysis of design features that nurses perceived as having a positive impact on information processing tasks performed during clinical reasoning. The first design feature that will be discussed is that of design principles **2e** and **5a**, which were incorporated into a single design feature. Design principle **5a** is concerned with ensuring that each variant (or data point) has a label printed above it, with design principle **2e** establishing that the label should present the value of the variant. The developer for the project chose to instantiate labels with values above the systolic and diastolic blood pressure, as it was felt that the chart would become too cluttered if labels were to be added for each data point. This is a logical decision, as the blood pressure graph area has a larger area for adding the labels; while space is more limited in other vital sign plot areas.

With regard to the impact of these design principles, the design feature of *value labels added to data labels* was identified 5 times during the interviews as being a useful design feature. In particular this design principle was seen as being useful when interpreting a patient's vital signs, eith one nurse stating:

I suppose this one is better, the way you have the numbers and all on it.

This finding is consistent with the intended purpose of this design feature. It was stated in chapter 5, section 5.4.3.1:

In order to facilitate the user in interpreting information represented in a visual format, they must be able to support these basic empirical operations.

As such, it can be observed that instantiating a design principle that facilitates the user in perceiving ordinal values of vital sign data (*the fourth of the basic empirical operations identified*) has a positive impact on the perceived usefulness of the chart with regard to facilitating the nurse in interpreting information presented on a chart. These design features were also identified as being helpful when discriminating between relevant and less relevant information and predicting outcomes. This is logical as the phases of sense making are not mutually exclusive (Benner & Tanner, 1987) and facilitating any one task is likely to also have a positive impact on the performance of other tasks.

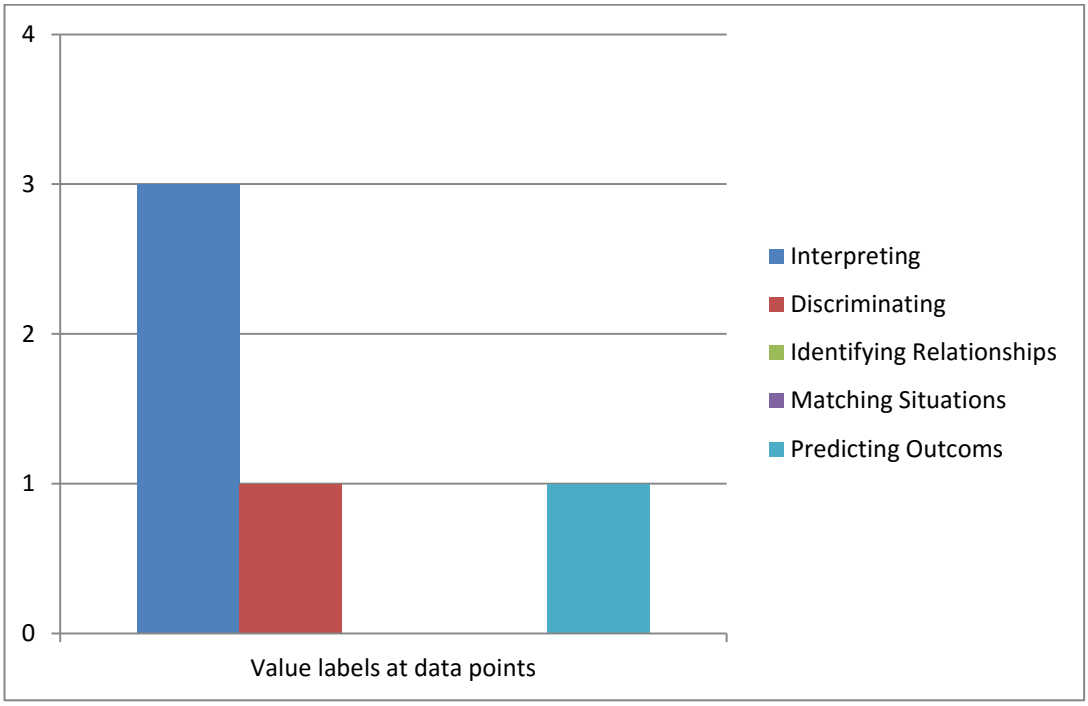


Figure 6.7. Impact of design principles 2e and 5c.

The next design principle to be discussed is concerned with design principles **4e** and **7e**, which were instantiated as a single design feature. This design feature was instantiated as the use of black dots on individual vital signs for graphed vital signs and up and down arrows for systolic and diastolic blood pressure. These shapes were used to establish closure for objects (graphs) and to maintain consistency with the

user's stored knowledge. Establishing closure for objects is designed to facilitate the user in detecting objects and patterns among objects. Maintaining consistency with user's stored knowledge is desired as it reduces the cognitive cost for individuals reviewing interfaces.

With regard to specific mentions during the interviews, the solid black dots on the graphs were identified twice as having a positive impact on interpreting charts, with the arrows being identified once as having a positive impact on nurse's ability to match situations. Again these findings are logical as the instantiation of a design feature that supports the Gestalt quality of closure is designed to facilitate the basic empirical operation of determining the equality of intervals or differences. Support for Gestalt qualities is also an important component for facilitating the user in identifying patterns. It is therefore also logical that this design feature would have a positive impact on matching situations, as an antecedent of matching situations is being able to identify patterns. The task of matching is defined as *comparing observed facts or patterns to one's own prior knowledge, drawing analogies from the context being observed to another context* (Baker et al., 2009, pg. 534). As such, any design feature that facilitates the identification of objects is likely to have a positive impact on a user's ability to match situations. A more telling quote regarding the usefulness of this particular design feature was made during the comparative evaluation of the eNEWS V1.0 and NEWS charts, where a nurse observed:

> *I don't know about the way the blood pressure is marked on it. I don't know if I agree with that, because there is no arrows up and arrows down, now is that 190? Or is that 189? Or is that 191? We would tend to write a number sometimes if we are very concerned about a high blood pressure or a low blood pressure, we would write the 190 or the 160 over the line.*

What can be inferred from this quote is that the absence of arrows from an object is likely to negatively impact the individual nurse's ability to accurately identify objects. With another nurse observing during the same round of interviews:

> *There is another thing, the arrows (on the blood pressure) we are used to that. Some places use a down arrow, we use the up arrow. Then again I would be quite institutionalised in that regard, I would*

like the little arrow. And a dot (A round dot to mark specific vital signs) and the line between them to make it look totally authentic.

This quote speaks to the nurses' preference for employing design features that are consistent with their stored knowledge. In this regard the implementation of design principles **4e** and **7e** appear to have had the desired impact on the perceived usefulness of the chart.

6.3.5. Design Features Not Identified as Having a Positive Impact, a Possible Explanation.

As observed in section 6.2.3, a number of design prescriptions from the framework for REVIEWS V0.1 were instantiated in the design of the eNEWS V2.0 chart. Section 6.3.4 presented a number of the newly instantiated design features that nurses identified during interviews as being useful to them when performing specific information processing tasks while using the chart. However, a further theme that emerged from analysis of the interviews is that a number of the new design features instantiated on the eNEWS V2.0 chart were not identified by nurses as being beneficial to them when conducting particular tasks. It is therefore the purpose of this section to discuss these design principles and present a possible explanation for the fact that these design features were not identified.

Specifically, design principles **2c** and **3b** were not identified during the final round of interviews as being useful to them when performing information processing tasks. Design principle **2c** is instantiated on the eNEWS V2.0 chart in the form of presenting the standard format for instructions for understanding the NEWS score. The standard was identified on the original paper-based NEWS chart and was replicated on the eNEWS V2.0 chart. The purpose of this design feature is to facilitate the user in perceiving the ordinal value of vital sign data. Design principle **3b** is instantiated on the eNEWS V2.0 chart as parameter values being added to the right hand edge of the chart area, with the principle being concerned with facilitating the user in perceiving the quantitative value of data. This design feature is already instantiated in the paper-based NEWS chart.

While these design features were not identified specifically by nurses as having a positive impact on the design of the chart, this is likely due to the nature of the comparative evaluation. As the paper-based NEWS chart was also present in the

comparative evaluation, the design features were likely not to have been considered to be novel and as such, nurses did not feel it was necessary to mention. While the design features were not mentioned specifically, the inclusion of the features is reflected in the answers to the final questions of the interviews. The final question presented an opportunity for nurses to identify any design features that may not have been discussed previously in the interview. Of all of the nurses interviewed none of the nurses concluded that any important design features were missing from the chart. 1 nurse questioned the inclusion of bowel movements in the chart as this was not included in the original paper-based NEWS chart, 1 nurse questioned the format of the nurse PIN and 1 nurse requested a different time format. However, all of the nurses said that there were no design features missing, with one nurse stating:

> *No, it has to be more or less the same as this because this is the national score; it has to be more or less the same as that. Now it is pretty* (good)*, I'd have to study it more, to make sure nothing is missing…. No that's it, I think you've done a great job really; you've covered a lot of it.*

With another nurse observing that:

> *Nothing is missing.*

Again, this is a reflection of nurse's preference for using charts that they are more familiar with as observed in section 6.3.3. While it is not possible to formally establish the usefulness of these design principles, it is likely that not including them would have a negative impact on nurse's perception regarding the usefulness of the chart. This observation is based on analysis of the comparative evaluation of the eNEWS V1.0 chart and the paper-based NEWS chart presented in chapter 4. In this evaluation nurses identified a number of design features that were instantiated in the paper-based NEWS chart, but were not present in the eNEWS V1.0 chart. Section 4.3.4.2 observed that 3 nurses observed the fact that the *instructions for use* were not present on the eNEWS v1.0 chart and this could have negatively impacted the usefulness of the chart.

6.3.6. Building on the Strengths of an Electronically-Generated Observation Chart

Sections 6.3.4 and 6.3.5 presented an analysis of the impacts of new design features that had an impact on the usefulness of the eNEWS V2.0 chart in comparison to the paper-based NEWS chart and the eNEWS V1.0 chart. A further theme that emerged from the evaluation of the eNEWS V2.0 chart was the strength of the design features that were initially instantiated in the eNEWS V1.0 chart. In chapter 4 a number of design features were identified as having a positive impact on the perceived usefulness of the eNEWS V1.0 chart. The design feature: '*bold graph lines for graphing patient vital signs over time*' was observed as having a significant impact on the perceived usefulness of the chart with regard to supporting information processing tasks. These observations were reflected in the analysis of the interviews when evaluating the eNEWS V2.0 chart. In this case nurses made numerous observations regarding the usefulness of the design of the graph. As observed in section 6.3.4, a number of nurses noted the usefulness of the arrows and dots in relation to improving the graph. While nurses found it difficult to articulate why the graph was an improvement over previous charts, the clarity of the chart was regularly mentioned regarding the design of the eNEWS V2.0 graph. The following extract from an interview demonstrates this observation:

> ***Interviewer****: OK, so I suppose next we'll talk about discriminating between more and less important information. If you were to look at this chart is there any particular information you would look at straight away and you would be worried about?*
>
> ***Nurse****: I would look at the pulse rate here.*
>
> ***Interviewer****: And what is it that draws your eye to it? Is it the spike?*
>
> ***Nurse****: It's the big discrepancy; the spike makes it very clear, the line is clear.*
>
> ***Interviewer****: When you say that, do you mean that it is clearer than previous versions of it or would you say that when you look at the paper ones, that they are just as clear?*

> ***Nurse**: Well, it's clearer; it's more striking than the biro/pen really. It's more striking.*

With another nurse observing when asked about how the chart may support making predictions for a patient:

> *Yeah, well to be honest it makes you more aware of the acute changes in this gentlemen's care or condition. The spikes draw your attention immediately, the clear numbering of the blood pressure results draw your attention immediately, if that EWS was printed as 17, when you see the EWS written down here where it was 1 previously and it is 17 now and it correlates with the spikes in the chart.*

What can be observed from these extracts is that the clarity of the chart refers to an accumulation of design features. It encompasses design features such as; *continuously graphed lines, labels on data points, familiar shapes used for closure and bold/thick graph line*. While it would be preferential if the nurses could precisely articulate design features that they find useful, the theme that the chart is found to be clearer is a desirable outcome. The observation that the clarity of the design of a chart is important is consistent with Parsonson & Baer, (1978) who state that the utility of a chart is in terms of its communication function *very dependent on concise, descriptive figure titles, clear identification of scale variables and scale units and data presentation that emphasizes clarity, precision and ease of assimilation.*

Section 6.3.4 presented analysis of specific design features that nurses were able to identify as being useful, with section 6.3.5 discussing why some design features may have been useful despite nurses not having articulated their perceived utility. This finding that the nurses consider the clarity of the chart to be a major contributing factor to the improvement in the design is likely a reflection on the accumulated impact of multiple successfully designed and instantiated design features.

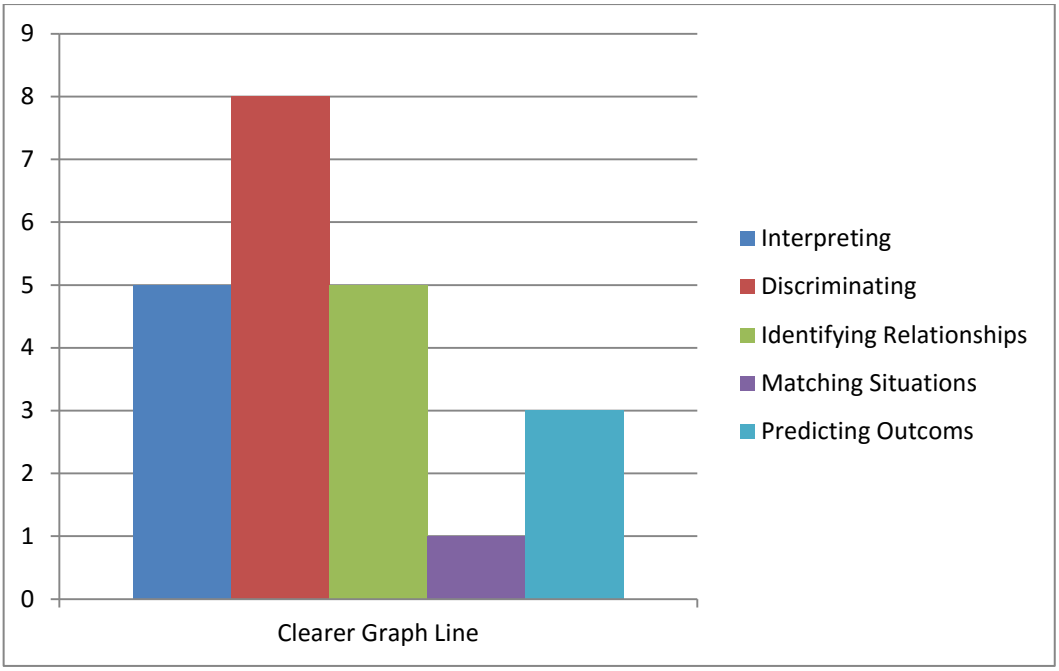


Figure 6.8. Analysis of perceived utility of "Clearer Graph Line" from evaluation of eNEWS V2.0 chart.

Figure 6.8 presents an analysis of how often the clearer graph line was identified in interviews as being useful for supporting specific tasks performed during the information processing phase of the clinical reasoning process. What can be observed from the chart is that *'clearer graph lines'* was identified as being useful for each of the tasks. Nurses found the clearness of the graph to be particularly useful when discriminating between important and less important information. Clearer graph lines were also mentioned 5 times for supporting interpreting and discriminating respectively. The observation that the clearer graph line being useful for all of the tasks performed is a reflection on the nature of the clear graph line being an accumulated design feature. It is logical that: a clearer graph line will support initial interpretation of data, that it will facilitate identifying more important information presented on an interface and that a clear graph line will support identifying relationships in data. However, during the interviews performed for the comparative evaluation of the eNEWS V1.0 and NEWS chart, the clarity of the chart was only noted once as being a contributing factor regarding the usefulness of the chart.

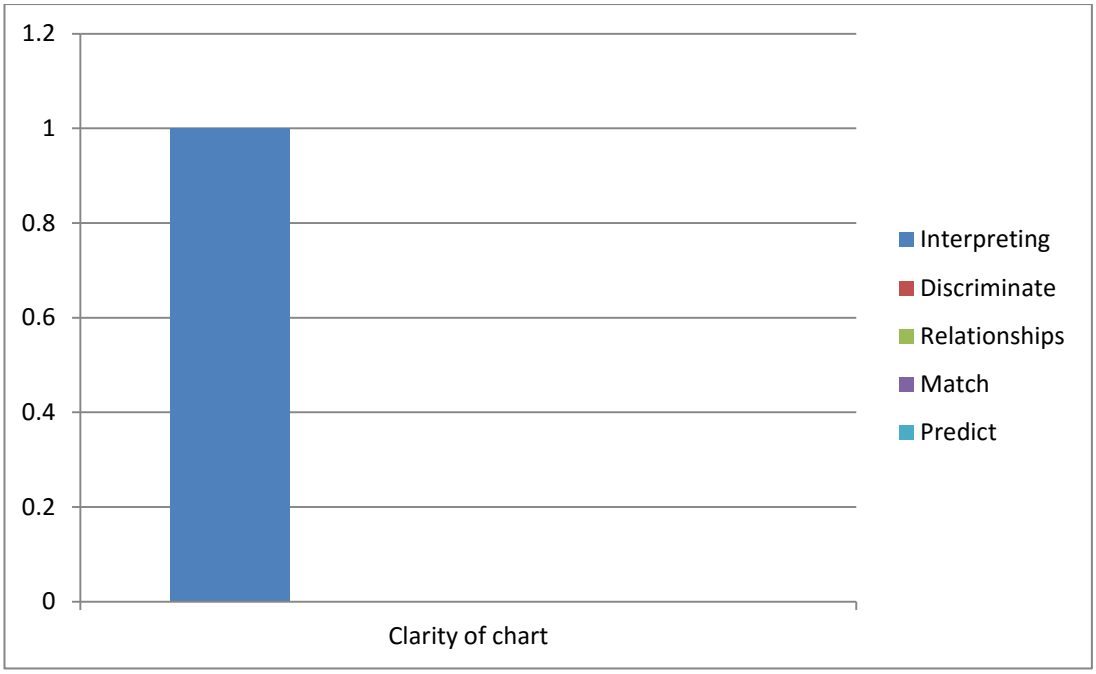


Figure 6.9. Analysis of perceived utility of "Clearer Graph Line" from evaluation of eNEWS V1.0 chart.

During the comparative evaluation of the eNEWS V1.0 chart, nurses were able to articulate specific design features that impact the usefulness of the chart both negatively and positively. This is likely due to the differing designs of both the paper-based NEWS chart and the electronically generated eNEWS V1.0 chart. As such, they were able to be more critical of the design of the novel eNEWS chart. However, in the case of the design of the eNEWS V2.0 chart, it was more consistent with the user's stored knowledge and they were less able to identify specific design features that differentiated the two charts. Instead, nurses referred to the improved clarity of the chart. This is an important observation as it implies if an electronically generated observation chart is designed in a manner that minimises the perceived differences between the paper-based and the electronically generated chart, then there will be a positive impact on the perceived usefulness of the chart. When this has been achieved as a minimum standard, nurses are then likely to appreciate the usefulness of a "clearer" chart that can be generated by an electronic system.

6.3.7. Arriving at V1.0 of the Framework for REVIEWS

While chapters 5 and 6 have thus far focus on the design and instantiation of the framework for REVIEWS V0.1, V0.1 does not represent the final version of the framework to be presented in this thesis. The comparative evaluation of the eNEWS V2.0 chart and the analysis of these findings presented in section 6.3 produced further design knowledge that can contribute towards the utility of the framework. The design knowledge emerges from consideration of the experimental design features instantiated by Dr Simon Woodworth as described in section 6.2.3. These design features were designed based on feedback given by nurses during the comparative evaluation of the NEWS and eNEWS V1.0 charts and correspond to design principles **4b** and **7c.**

- **4b** *In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of similarity, should be supported.*
- **7c** *In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.*

These design features take advantage of the computerised nature of the eNEWS system, where data collected through the interface can be easily dynamically analysed and the data can then be presented in a manner which gives context to the data. The design features were:

- Area for presenting individual and aggregate weighted vital sign scores are colour coded based on the calculated score.
- Vital sign graph lines are dynamically coloured. Red indicates a rise in EWS score, Green indicates a decrease and Black indicates no change.

When discussing these design principles it was observed that the inclusion of the design principles caused confusion for nurses who were not familiar with the design features. This observation is consistent with design principles concerned with *consistency with user's stored knowledge*, where it is advised that design principles should be as consistent as possible with the user's stored knowledge. However, this begs the question of how can new design features be introduced and easily integrated

into the nurse's workflow. The answer appears to be relatively straightforward with the following extract from an interview being demonstrative of the potential solution:

> ***Nurse:*** *Yeah the colour coding I suppose, the green and red if they program would do it itself, that's something I would probably get used to, not having seen it before, I understand what you are trying to do, having a green going up and a red coming down.*
>
> ***Interviewer:*** *Yeah, but maybe as it is the colours aren't bright enough?*
>
> ***Nurse:*** *No its fine brightness wise, I just didn't understand it initially and now that I understand it, I like that aspect of it.*

If *instructions for use* as a design principle had been introduced to help to explain any new design features then it is likely the utility of the features would have been greater. When comparatively evaluating the eNEWS V1.0 chart and the paper-based NEWS chart in phase two, it was observed that the eNEWS V1.0 chart did not have instructions for understanding the colour coding system, with nurses considering this to negatively impact the usefulness of the chart. As such, this feature was introduced in the eNEWS V2.0 chart to explain the standard NEWS colour coding system. However, instructions for use were not introduced to explain the experimental design features. Therefore it is logical that the following design principle should be added to the framework. The complete set of design principles that constitute the framework for REVIEWS V1.0 can be seen in Appendix 8.

Support for Novel Design Features	
9a	In order to support the integration of novel design features on observation charts, instructions for using the novel feature should be incorporated into the chart design.

6.4. Discussion

The purpose of this chapter was to demonstrate how the framework for REVIEWS V0.1 (formalised in chapter 5) could be practically instantiated and to demonstrate the utility of the framework. In order to demonstrate how the framework could be

utilised, the framework was applied to the electronically generated eNEWS V1.0 chart. The first phase of applying the framework is to systematically analyse the eNEWS V1.0 chart from the perspective of the framework V0.1 and establish which design principles have not already been adequately instantiated in the chart. This was presented in section 6.2.1. This analysis established that a number of prescriptive principles were not adequately instantiated in the eNEWS V1.0 chart. These principles were established in section 6.2.2.

	Design Principle
2c	In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.
2e	In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.
3b	In order to facilitate the user in perceiving the quantitative value of data, parameter values should be written on both sides of the chart.
4e	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.
5a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.
7b	In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.
7e	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.

Table 6.10. Framework for REVIEWS V0.1 design principles not instantiated in eNEWS V1.0 chart.

Section 6.2.2 then presented how these design principles could be practically instantiated in the electronically generated eNEWS chart, with the result of the instantiation process taking the form of the eNEWS V2.0 chart as presented in

section 6.2.3. The design principles presented in Table 6.10, were then practically instantiated as the following design features:

- Standard format for instructions for understanding NEWS scores from HSE's paper-based NEWS chart used presented on chart.
- Labels for systolic and diastolic blood pressure are presented above and below the graph.
- Parameter values are added to the right hand edge of the chart area.
- Black dots are added to data points where vital signs are graphed.
- Up and down arrows are added for diastolic and systolic blood pressure.
- Chart is designed using vector graphics, so chart can be printed at A3 size without distorting the clarity of the graphic.

Two further experimental design features were also instantiated in the eNEWS V2.0 chart, these were:

- Colour coding area where EWS scores are presented, using standard colour coding system.
- Colour coding graph lines to indicate improvement (green) or dis-improvement (red) in vital sign values.

In order to demonstrate the utility of the framework, interviews were performed with 9 nurses who had experience with using the paper-based NEWS chart. The purpose of these interviews was to comparatively evaluate the Irish HSE's paper-based NEWS chart, the eNEWS V1.0 chart and the eNEWS V2.0 chart. The interviews were structured to capture information regarding the usefulness of specific design features instantiated in each chart in terms of facilitating five tasks performed during the information processing phase of the clinical reasoning process. Having performed and transcribed the interviews, inductive analysis of the interview scripts was then performed to help identify emerging themes from the interviews.

The overall theme that emerged from the interviews was that the eNEWS V2.0 chart was considered to be more useful than both the paper-based NEWS chart and the electronically generated eNEWS V1.0 chart. This was a desirable finding as the previous comparative evaluation of the eNEWS and eNEWS V1.0 chart demonstrated that nurses found the two charts to be as useful as each other. The

finding that the eNEWS V2.0 chart was perceived to be more useful than both the NEWS and eNEWS V1.0 charts demonstrates that the framework for REVIEWS V0.1 has a positive impact on the utility of the chart.

Another theme that emerged in section 6.3.4 was that a number of design features were identified as having a positive impact on specific information processing tasks. These design features were designed based on specific design principles that were intended to impact specific tasks. For example, the design feature *'print value labels at data points'* was designed specifically to *facilitate the user in perceiving ordinal values of vital sign data*. Perceiving ordinal values of data is an important component in facilitating a user in the initial interpretation of data and section 6.3.4 demonstrated that nurses perceived this design feature as having a positive impact on the interpreting task. Furthermore the design features: *'add black dots to data points on graphs'* and *'add up and down arrows to systolic and diastolic blood pressure data points'* were also identified as having a positive impact on the tasks they were design to impact. The experimental design features were also identified as having a positive impact on the usefulness of the eNEWS chart, however, the usefulness of these was negated by not including instructions for understanding the design features on the chart itself.

While a number of design features were specifically identified by nurses as having a positive impact on information processing tasks, a number of design features were not identified during the interviews as having a positive impact on information processing tasks. These features include: *'Standard format for instructions for understanding NEWS scores from HSE's paper-based NEWS chart used presented on chart', 'parameter values are added to the right hand edge of the chart area' and 'chart is designed using vector graphics, so chart can be printed at A3 size without distorting the clarity of the graphic'.* While these design features were not identified specifically, this is likely due to the fact that these features had already been instantiated in the paper-based NEWS chart and as such, were not considered by nurses to be novel. However, the importance of adequately instantiating these features emerged from the final question of the interviews. The final question of the interviews was design as a sanity check to ensure that nothing had been missed during the interview and to see whether any design features had not been adequately

instantiated or whether the interviewees had any ideas for potential improvements. During the second data collection phase presented in chapter 4, the NEWS and eNEWS V1.0 charts were comparatively instantiated and in this case the nurses identified a number of design features that were present in the NEWS chart that were not instantiated in the eNEWS V1.0 chart. However, in the third data collection phase presented in this chapter, nurses could not identify any design features that were instantiated in the NEWS chart that were not instantiated in the eNEWS V2.0 chart. This finding is likely to have been a significant contributing factor to the overall perceived usefulness of the eNEWS V2.0 chart.

The final theme that emerged from analysis of the findings was the importance of the perceived clarity of the eNEWS V2.0 chart. Section 6.3.6 presents a discussion of this theme and established that the perceived clarity of the chart is likely a consequence of a number of design features instantiated in the eNEWS chart. Furthermore, it is also a consequence of using electronic systems to create the charts rather than relying on humans to manually enter the vital signs on the NEWS chart and requiring them to manually graph the vital signs.

The themes that emerged from the interviews demonstrated that the application of the framework for REVIEWS V0.1 had a significant positive impact on the perceived usefulness of the electronically generated chart. Some of the design features that emerged from the application of the framework V0.1 were specifically identified as having a positive effect on the tasks they were designed to impact. However, it would have been desirable for this research to demonstrate the specific effect that each design feature had on specific tasks. This is likely to be a consequence of the evaluation method chosen. The method chosen was necessary as earlier data collection phases required that the interviewees were able to provide richer feedback on the usefulness of the charts and for them to be able to engage with the interviewer to allow them to identify potentially useful design features that had not been adequately instantiated. Furthermore, it was necessary to repeat the evaluation method in this phase of data collection in order to ensure that the results of the data could be comparable to previous findings. However, a more structured evaluation method may have facilitated demonstrating the utility of specific design features in the context of specific information processing tasks. Future evaluations of

the framework may benefit from an evaluation method that allowed for these types of findings.

The findings from this chapter are desirable with regards to the objective of the research project. The objective of the research is defined in chapter 1 as:

> *To investigate and produce a set of design principles, which when instantiated, have a positive impact on* nurses *ability to process information presented on an electronically generated vital sign chart. The set of design principles will be referred to as the framework for REVIEWS*

Chapter 5 presented the design principles that constitute the framework V0.1, with this chapter presenting how the framework can be practically instantiated and the evaluation of the instantiated framework. Furthermore, this chapter demonstrated that the framework, when instantiated, has a positive impact on nurses perceived ability to process information presented on an electronically generated AWTTS observation chart. Considering these observations it can be stated that the framework for REVIEWS adequately achieves the utility requirements it was designed to affect. However, some issues were discovered regarding the introduction of experimental design features that were designed as an initial step to introduce intelligent computational analysis to observation chart. Chapter 7 will represent the *Communication* phase of the updated DSRM process model and will reflect on the findings of the evaluation presented in this chapter to communicate the final version of the framework to be presented in this thesis.

Chapter 7 : Reflecting on the Design Process and Communicating the Theoretical Findings, the Research Contributions and Opportunities for Future Research

7.1. Introduction

The purpose of this chapter is to present the final iteration of the framework for REVIEWS, to discuss the emergent theoretical findings from this research and to discuss the consequences of the research for both industrial and academic audiences and to discuss the limitations of the study and potential avenues for future research. In order to formalise the final version of the framework, section 7.2 presents a reflection on the search process, the evolution of the framework and the findings of the evaluation of the framework V1.0 as presented in chapter 6. In the course of this thesis a number of findings have been observed which have contributed towards the final iteration of the framework; these findings have had a theoretical and methodological impact on the research. Section 7.3 presents these emergent findings and discusses the impact of these findings for academic audiences. An important component of any scientific endeavour is to consider the utility of the findings for potentially interested industrial audiences. Section 7.4 discusses academic contributions of this research and potential opportunities for future research. In the case of Design Science Research (DSR) and in cases where health applications have been designed there is a natural relationship between the research and industrial applications. This relationship is discussed in section 7.4.4. The limitations of this research are presented in section 7.5, followed by concluding remarks in section 7.6.

7.2. The Emergence of the Framework for REVIEWS V1.0

The purpose of this section is to demonstrate the logical emergence of the framework for REVIEWS presented in this thesis. Version 1.0 of the framework is the culmination of a search and theorisation process that began with chapter 1 and was finalised with chapter 7. As such, prior to presenting the final iteration of the framework, it is useful to first present a brief summary of chapters 1 to 6 and the principle contributions of each of these chapters towards the design of the framework.

7.2.1. The Literature Search and the Methodology Refinement

The prior research project this thesis is associated with is a Science Foundation Ireland (SFI) funded investigation into the design and implementation of an electronic version of the Irish Health Service Executive's (HSE's) National Early Warning Score (NEWS) system for patient observation charts. The motivation for the research topic of this thesis, allied to the prior research, was the need for better design of patient observation charts to improve the information-processing phase of the clinical reasoning process. This is an important area of investigation due to the complexity of the information processing required and its relevance to information systems research. The research objective was identified in chapter 1 as:

> *To investigate and produce a set of design principles, which when instantiated, have a positive impact on health care professional's ability to process information presented on an electronically generated vital sign chart. The set of design principles will be referred to as the framework for REVIEWS.*

Having discussed the context of the research project in chapter 1, chapter 2 presented an understanding of Early Warning Systems (EWS) design and the current state of the art for Aggregate Weighted Track and Trigger System (AWTTS) chart design literature. Through exploring EWS design literature and considering the Irish HSE's NEWS system it was established that the design of an observation chart to support clinical reasoning should not seek to replace the human decision maker in the clinical reasoning process and should instead seek to support the tasks they perform when making care decisions for patients. By exploring the observation chart design literature it was established that a small pool of relevant literature exists. The literature base is primarily output by the group who prepared the report for the Australian Commission on Safety and Quality in Health Care (Preece et al., 2009). This literature sought to employ heuristic evaluation of existing charts to identify useful design features for an observation chart. Chapter 2 concluded that the existing observation chart design research employed a broad and shallow literature review approach to understand the heuristic principles for chart design.

Chapter 3 presented the metaphysical position of this research, the research approach and a high level research design for this study. From a metaphysics perspective this

research considered ontology, epistemology and methodology and situated itself in a critical realist paradigmatic perspective. Chapter 3 also established that this research would employ a Design Science Research (DSR) approach and the focus of the research would be to create a set of design principles to guide the design of electronic observation charts. DSR seeks to understand and explain phenomena and create descriptive prescriptions (*design principles*) for manipulating a problem system based on an understanding of the phenomena (Gregor, 2006). Chapter 3 established that an updated version of Peffers et al.'s, (2008) Design Science Research Methodology (DSRM) process model would be employed to structure the design of the framework.

A further practical methodological consideration that arose from the nature of the research project was the necessity to understand and evaluate situated artefacts on which this research iterates. As such, an inductive process for discovering and synthesising design knowledge for situated artefacts was developed and presented in section 3.4.1. Chapter 3 also established that this research would employ a naturalistic evaluation method where semi-structured interviews would be conducted to collect data regarding the usefulness of the artefacts being evaluated.

7.2.2. The Emergence of the Framework for REVIEWS Version Alpha and Beta

Chapter 4 presented the initial two data gathering phases for this research. These phases both utilised an inductive approach to discover and synthesise design knowledge pertaining to the Irish HSE's paper-based NEWS chart and the electronically-generated eNEWS chart developed by the Health Information Systems Research Centre (HISRC) in University College Cork (UCC) respectively. Based on the design knowledge synthesised during these phases semi-structured interviews were conducted to establish the comparative utility of the respective charts; both paper-based and electronically generated. Analysis of these interviews demonstrated that the paper-based NEWS chart was perceived to be more useful than legacy charts that nurses had been using and the eNEWS chart was considered to be at least as useful as the paper-based NEWS chart. The data gathered during these evaluations also provided secondary findings in terms of highlighting design features that nurses

considered to be useful and suggestions for future design features for the eNEWS system.

The principle contributions that emerged in chapter 4 are the development of the initial two iterations of the framework for REVIEWS. The framework version Alpha was developed from the knowledge discovery process presented in phase one. Version Alpha is a reflection of the early phases of this research project where knowledge regarding the design principles embedded in the NEWS chart was immature. Furthermore, the extent of the impact of the design principles on the problem system was not yet known. To this extent version Beta of the framework (presented in section 4.3.1.2) represents a more mature design framework. The framework version Beta incorporates empirical design knowledge formalised from the evaluation of the paper-based NEWS chart and from inductive analysis of design features instantiated on the electronically generated eNEWS chart. The framework version Beta demonstrates the current understanding of the impact of specific design features on information processing tasks.

Both the Alpha and Beta versions of the framework represent important evolutions in the studies' understanding of the design knowledge necessary to formulate the framework. The Alpha version allowed for an initial understanding of the problem system and some tentative design principles and from this knowledge the comparative evaluation methodology for this research could be formalised. As the design theory was to positively affect the tasks performed during the information processing phase of the clinical reasoning process, the evaluation methodology for all evaluations presented in the three research phases was designed to evaluate how well design features instantiated in the observation charts were perceived as helping nurses to perform these tasks. The Beta version of the framework then represented a deeper understanding of the design principles and the extent to which nurses perceive these design principles as impacting the information processing tasks. This knowledge is useful as it demonstrates the importance of specific design principles. It also implies that specific design principles may not yet have been adequately instantiated in order to have a positive impact on information processing tasks.

7.2.3. The Deductive Design Process for the Framework for REVIEWS V0.1

Having formalised an understanding of the situated observation charts that are pertinent to this research, chapter 5 then presented the initial design phases of the updated Design Science Research Methodology (DRSM) process model necessary to formalise the framework for REVIEWS V0.1. This research employs an updated version of the DSRM process model (presented in section 3.3.3.1) as developed by Peffers et al., (2008). Chapter 5 presented the *development of the utility requirements, development of the kernel knowledge* and the *design and development* phases of this model. These phases represent design knowledge development phases of the updated DSRM process model. Theories from cognitive fit, sense making, clinical reasoning, visual representation and semiology of graphics literature is leveraged in this chapter. This theoretical knowledge is then reconciled with the theoretical and practical findings that emerge in chapter 4. Considering these theoretical and practical findings then allows for the formalisation of a set of coherent and comprehensive design prescriptions that constitute the framework V0.1 (presented in section 5.5.4).

Chapter 6 then presented the *demonstration* and the *evaluation* phases of the updated DSRM process model. The *demonstration* phase presents how the design framework V0.1 can be practically instantiated. For this research the eNEWS chart was analysed to identify design principles from the framework V0.1 which established that seven of the design principles were not adequately instantiated in the eNEWS chart. Based on these seven design principles six design features were suggested for development, which if instantiated, would result in all of the design principles that constitute the framework V0.1 being adequately instantiated in the eNEWS chart. The result of this development process was the eNEWS V2.0 chart.

The *evaluation* phase presented a comparative evaluation of the paper-based NEWS chart and the electronically generated eNEWS V1.0 and eNEWS V2.0 charts. Analysis of the data collected in this evaluation demonstrated the utility of the design framework V0.1. It was established that the eNEWS V2.0 chart was considered to be significantly more useful than both the NEWS and eNEWS V1.0 charts from the perspective of all of the tasks performed by nurses during the information processing

phase of clinical reasoning. This analysis of the data presented in chapter 6 demonstrates that the framework V0.1 had the desired impact on the problem system, with nurses finding it difficult to identify any area of weakness in the design of the chart. As such, it was established that the framework had met the goal of a design theory in DSR i.e. it produced a satisfactory artefact (S. T. March & Storey, 2008; Simon, 1988). While the framework for REVIEWS has had the desired impact on the problem system, the introduction of experimental design features as described in section 6.2.3 also presented some additional unexpected results for this research. The knowledge that emerged from these findings is represented in the framework V1.0 (*section 6.3.7)*. Table 7.1 presents the structure of the research phases that allowed for the design of the framework for REVIEWS V1.0 and the iterative development of the eNEWS V2.0 observation chart.

	Problem Formalisation		*New Design Input*	
	Phase 1 Nov 2013	***Phase 2 Feb 2014***	***Phase 3 Dec 2014***	***End***
Purpose of Design Phase	***Reflect on design and usefulness of the paper-based NEWS chart.***	***Reflect on design and usefulness of the electronic eNEWS V1.0 chart.***	***Introduce deductive design theory development process to help create eNEWS V2.0.***	
Practical and Academic Design Knowledge	**What tasks does the chart support?** **What design features support each task?**	**What can the previous evaluation tell us?** **To what extent do design features support tasks?**	**What can the previous evaluation tell us?** **What theoretical knowledge can be leveraged to improve chart design?** **How can these theories be leveraged?**	**What can the previous evaluation tell us?** **What can the design process tell us?**
Resulting Design Artefact	***Tentative Design Theory*** ***REVIEWS Alpha***	***Tentative Design Theory*** ***REVIEWS Beta***	***REVIEWS V0.1*** ***Consists of 23 Design Principles***	***REVIEWS V1.0*** ***Consists of 24 Design principles***
Comparative Evaluation	**NEWS Vs. Legacy Charts**	**eNEWS V1.0 Vs. NEWS**	**eNEWS V2.0 Vs.** **eNEWS V1.0 Vs.** **NEWS**	

Table 7.1 Structure of research phases 1, 2 and 3.

7.3. Discussing Theoretical Findings

The purpose of this section is to present the original theoretical findings presented in this research. These findings emerged from two sources: first, the design search process and second the comparative evaluation of both the paper-based (NEWS) and electronic observation charts (eNEWS V1.0 and eNEWS V2.0). The search process is an important phase in design, in order to address design issues there is a necessity to identify appropriate solutions in both academic and industrial literature. The principal theoretical findings that emerged from the search process include the formalisation of a useful *theory-led design approach* and the successful application of *sense making* and *cognitive fit* theory to observation chart design. These findings are discussed in more detail in section 7.3.1 and 7.3.2. The principal theoretical finding that emerged from the comparative evaluation of the paper-based and electronically generated observation charts (presented in chapter 6) was the significant positive impact of the framework for REVIEWS. These findings are discussed in section 7.3.3.

7.3.1. The Utility of Employing a Theory-Led Design Approach for Observation Chart Design

An important deviation in the design of the framework for REVIEWS from existing observation chart design research is the theory-led design approach employed. The theory-led design approach presented in this thesis was found to be an important component that contributed towards the successful design and evaluation of the framework for REVIEWS. Extant observation chart literature appeared to have taken a design-feature led design approach. This approach inherently reduces the perceived rigor with which design features are discovered and creates a disconnect between the theory that informs a design and the actual implementation of a design feature (Gleasure et al., 2012).

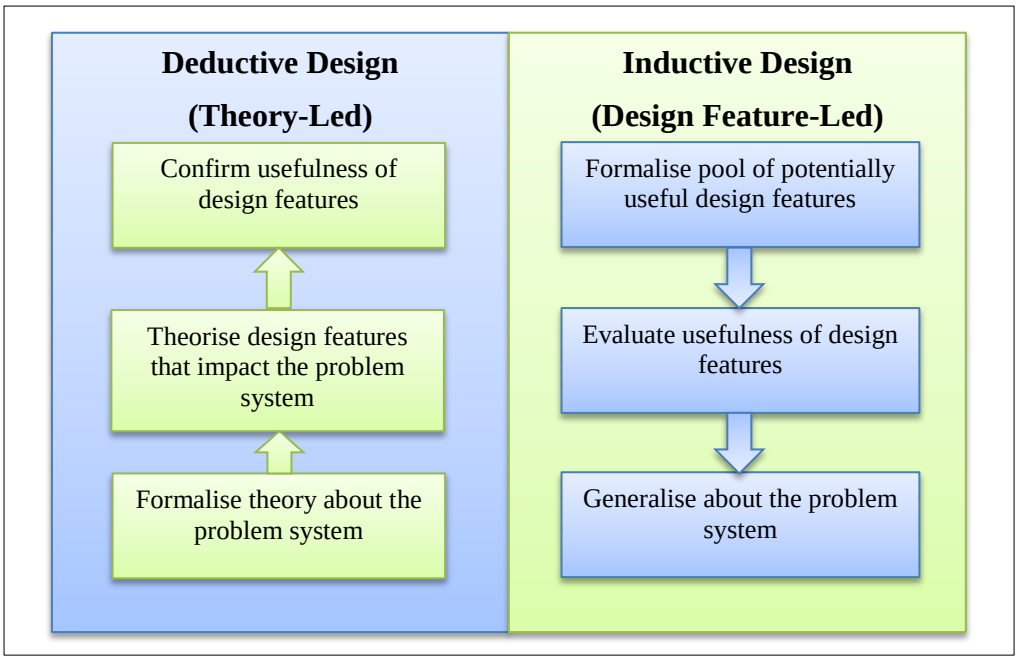


Figure 7.1 Logical flow of theory-led and design feature-led design.

The benefits of employing a theory-led deductive design approach can be seen in the evolution of the framework as presented in Table 7.1.

The initial two versions of the framework for REVIEWS were formalised through utilising inductive and empirical evidence to formalise tentative design frameworks. These design frameworks were useful and represented the understanding of the design principles that were instantiated in the NEWS and eNEWS V1.0 charts at the time of performing the research. Phase 3 of the research then introduced a deductive design approach. This phase leveraged extant literature and empirical knowledge gathered in phases 1 and 2 of the research to produce a cohesive and comprehensive set of design principles that constituted the framework V0.1. The benefit of employing a deductive design approach is reflected in the positive outcome of the comparative evaluation of the eNEWS V2.0 chart compared to the eNEWS V1.0 chart and the paper-based NEWS chart. Considering the benefit of employing this deductive approach it becomes logical to discuss the theorisation that was necessary to formalise the set of design prescriptions that constitute the framework V0.1. Section 7.3.2 presents this discussion.

7.3.2. The Relevance of Sense Making and Cognitive Fit Theory to Observation Chart Design

An important part of the design process was the search for theoretical knowledge that could contribute towards improving the design of observation charts. As mentioned above this research took a theory-led approach where theoretical knowledge is leveraged to improve the design of an artefact. The identification of sense making and cognitive fit literature and the applicability of the theory to observation chart design was a central finding that contributed towards the success of the framework for REVIEWS.

Cognitive fit theory was identified as a suitable theory as it strives to understand how interfaces can best be designed to support specific tasks (Vessey, 1991). This focus is appropriate as this research has identified the tasks that nurses perform during information processing and it is logical that an interface should be designed to best support these tasks. Cognitive fit theorists have posited that tasks performed when reading visual representations of data are either spatial (*assess the problem as a whole*) or symbolic (*extract discrete and therefore precise data values*). The NEWS chart is an example of a visual representation that has been designed to support both symbolic and spatial tasks. Table 7.2 presents a brief summary of the problem system tasks the NEWS chart has been designed to address, the type of task they represent and the approach the NEWS chart has taken to representing data for this task.

Problem System Task	Task Type	NEWS Visual Representation Approach
Aid initial assessment for acute illness.	Symbolic.	An initial assessment implies observation of a discrete set of results. In this case a table style representation is appropriate. The NEWS score is used to facilitate this assessment and a table style representation is utilised.
Aid continuous monitoring of patient's during their hospital stay.	Spatial.	Continuous assessment implies observing a set of values over time. This allows the nurse to observe improvements or degradation of patient's health over time. In this case a graphical plot is an appropriate means of visual representation. The NEWS chart provides an area for plotting data points over time.

Table 7.2. Analysis of the Irish HSE's NEWS chart in terms of cognitive fit.

By further exploring cognitive fit literature an analogous process to information processing during clinical reasoning was discovered. Sense making during data exploration was established as being comparable to information processing during clinical reasoning as the tasks performed during each process are related (presented in section 5.4.2). Table 7.3 presents the information processing tasks performed during clinical reasoning and the analogous tasks that are performed by individuals when making sense of data presented on an interface.

Information Processing During Clinical Reasoning	**Sense Making During Data Exploration**
Interpreting.	*Making inferences.*
Discriminating.	*Looking for outliers, observing specific data points.*
Identifying Relationships.	*Looking for patterns.*
Matching.	*Comparing observed facts or patterns to one's own prior knowledge, drawing analogies from the context being observed to another context.*
Predicting.	*Generating hypotheses about the data.*

Table 7.3 Tasks performed during information processing and sense making

This was an important finding as it implied that sense making research could then be applied to observation chart design. While it was established in chapter 2 that a shallow pool of observation chart design literature exists, sense making has a rich pool of literature from which to draw. The research presented in this thesis demonstrates the applicability of sense making literature for observation chart design through the applications of the model for aspects of visual representation that affect sense making as suggested by Baker, Burkman, & Jones, (2009) (as presented in section 5.4). Through successfully leveraging cognitive fit and sense making theory to improve the design of an electronic observation chart this research opens the door to future application of cognitive fit and sense making theory to the design of observation charts.

7.3.3. The Significant Positive Impact of the Framework for REVIEWS V0.1

The primary objective of this study was to improve on the design of an electronic observation chart. This was achieved through the formalisation of design principles that leverage theoretical knowledge from early warning system, observation chart design, cognitive fit and sense making literature, as well as practical knowledge captured during the design process. This ultimately resulted in the formalisation of the framework for REVIEWS V1.0 as presented in section 6.3.7. REVIEWS V1.0 was formalised through reflection on the instantiation of REVIEWS V0.1 as eNEWS V2.0 (*Section 6.2*) and the evaluation of eNEWS V2.0 (*Section 6.3*). The evaluation of eNEWS V2.0 demonstrated that the application of the framework for REVIEWS resulted in a significant improvement in the design of the eNEWS chart.

A comparative evaluation method was employed to evaluate the utility of the paper-based NEWS chart, the electronically generated eNEWS V1.0 chart and the eNEWS V2.0 chart. Semi-structured interviews were performed to gather data regarding the design of the observation charts in terms of how well nurses perceived each chart to support information processing tasks performed during clinical reasoning. Nurses were also asked to summarise their answers using 5 item Likert scales, with *1* implying that a chart did not help at all and *5* implying that the chart was very helpful. While the Likert scales were not considered to be a useful way of presenting generalisable findings, it was established that the Likert scales represented a good summary of how well nurses felt that each chart supported specific information processing tasks. The most significant observation that emerged from analysis of the interviews was that nurses considered the design of eNEWS V2.0 to be significantly better than both eNEWS V1.0 and the paper-based NEWS charts.

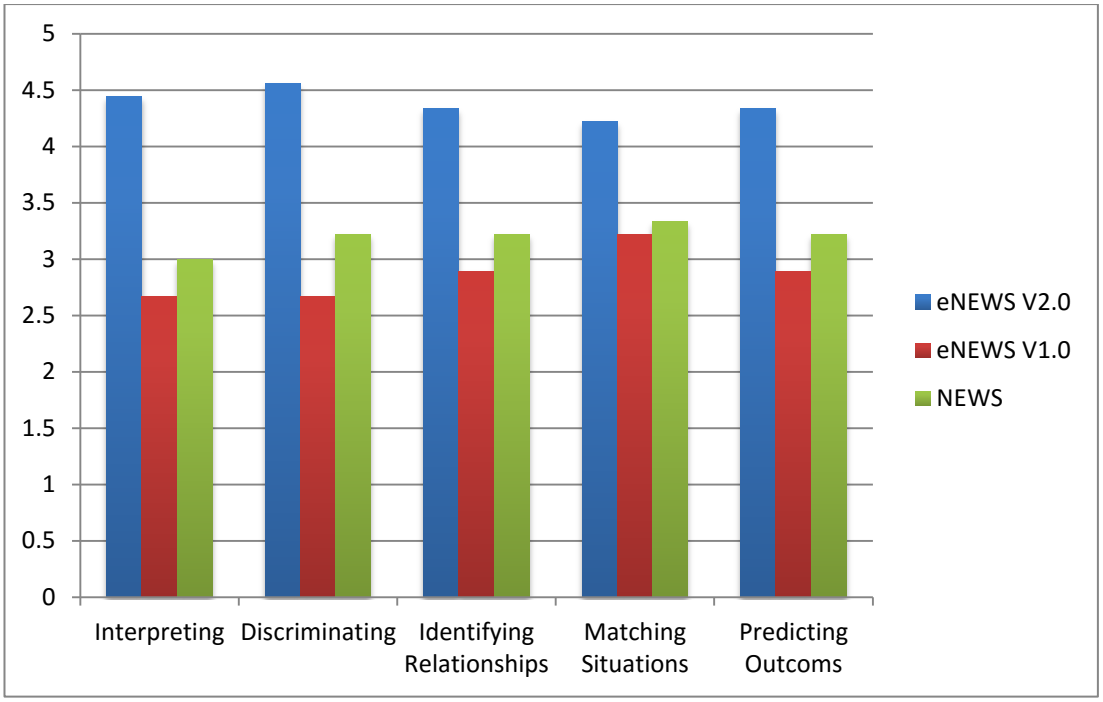


Figure 7.2. Summary of analysis of Likert scales for comparison of eNEWS V2.0, eNEWS V1.0 and NEWS charts.

More detailed analysis of the evaluation is presented in section 6.3. The findings of the analysis are significant as it allows for identification of a number of design features that contribute towards the improved design of the eNEWS chart. Furthermore, the positive results demonstrate the usefulness of the framework for REVIEWS. Analysis of the findings also helps to identify opportunities for future research as well as highlighting limitations of the research. Section 7.4 discusses the contributions of this research to academia and opportunities for future research, with section 7.5 presenting potential industrial applications of the research and opportunities for academia-practice innovation partnerships. Section 7.5 presents a discussion of the limitations of the research presented in this thesis.

7.4. Contributions of this Study and Opportunities for Future Research

As noted in section 7.2.1, this research employed a design science approach to structure the research. Design science by its nature is inherently related to and interested in practical problems, as such, the findings that emerge from this research are likely to have an impact on both academia and practice. Sections 7.4.1 and 7.4.3 will discuss the theoretical findings presented in section 7.3 and will outline both the

academic and industrial opportunities for further research. Section 7.4.4 will then discuss the contributions of this research to practice and potential areas for future academia-practice innovation partnerships.

7.4.1. The Framework for REVIEWS as a Nascent Design Theory

Gregor & Hevner, (2013) building on the work of Purao, (2002) posit that the research outputs from DSR can be different from the outputs of typical scientific enquiry and suggest that there are three maturity levels of artefacts that can emerge as outputs from DSR. A specific DSR project may produce artefacts on one or more of these maturity levels. The levels, as well as the contributions of the research described in this thesis are presented in Table 7.4.

The Framework for REVIEWS (V1.0)
Support for the Four Basic Visual Perceptual Approaches
Association, Differentiation, Ordered Perception, Quantitative Perception
Support for Gestalt Grouping Qualities
Proximity, Similarity, Symmetry, Good Continuity, Closure and Inference of Common Fate
Consistency with User's Stored Knowledge
Consistency with; The Invariant and the Components, The Number of Components, and The Length of Components
Support for Analogical Reasoning
In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.
Support for Novel Design Features
In order to support the integration of novel design features on observation charts, instructions for using the novel feature should be incorporated into the chart design.

Figure 7.3. Abridged version of the Framework for REVIEWS V1.0. Full version can be seen in Appendix 8.

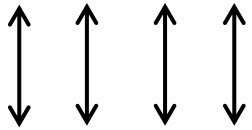
	Contribution Types	Example Artefacts	This Research
More abstract, complete and mature knowledge.	**Level 3.** Well-Developed design theory about embedded phenomena.	Design theories (mid-range and grand theories).	REVIEWS tests the boundaries of the theory, but not categorically a level 3 design theory.
	**Level 2.** Nascent design theory = knowledge as operational principles/architecture.	Constructs, methods, models, design principles, technological rules.	REVIEWS presents a set of prescriptive design principles which can inform the design of an electronic observation chart
More specific, limited and less mature knowledge.	**Level 1.** Situated implementation of artefact.	Instantiations (software products or implemented processes).	REVIEWS V0.1 is instantiated in the eNEWS V2.0 chart.

Table 7.4. Design Science Research contribution types. Adapted from: (Gregor & Hevner, 2013, p. 342)

The objective of this research has a focus on exploring the design of observation charts in order to formalise a set of design principles which is referred to as the framework for REVIEWS (Retrospective Evaluation of Vital Sign Information from Early Warning Systems). The design principles for the framework leveraged design knowledge regarding the purpose of the system as established in chapter 4 and the cognitive fit and sense making literature (as summarised in section 7.3.2). REVIEWS also represents the primary output of this research, the framework as an artefact can be primarily situated as a level 2 artefact (i.e. a nascent design theory). Gregor & Hevner, (2013) posit that an artefact can be described as a nascent theory if it demonstrates the design science qualities presented in Table 7.5.

Design Science Qualities	Framework for REVIEWS
1. Logical consistent set of statements.	The framework as presented in section 6.3.7 consists of twenty four prescriptive statements.
2. Constructs and statements are clearly defined with knowledge descriptions at an abstract level.	The abstract knowledge pertaining to the design principles is presented as kernel knowledge in section 5.4.
3. Method, constructs and algorithm are described in abstract terms without having recourse to the specific software implementation.	Design principles are described using general design principles as opposed to specific design features.
4. Contains technological rules (may be implicit).	Rules can be abstracted from each design principle.
5. Technological rules can be converted to an empirical generalisation such as a statement that can be tested.	Section 6.2.2 demonstrates how the design principles can be instantiated as specific design features.

Table 7.5. Analysis of the framework for REVIEWS as a nascent design theory

While Table 7.5 demonstrates how the framework can be described as a nascent design theory, it is also reasonable to state that this thesis presents further DSR outputs. A level 1 output may be an instantiation of a design theory, in the case of this research the application of the framework to the situated electronic eNEWS chart resulted in V2.0 of the eNEWS chart. This represents a level 1 output. While it can be confidently stated that this thesis produces outputs at levels 1 and 2, the thesis also outputs something close to a level 3 output. Gregor & Hevner, (2013) describe the process of developing design theory as a process of maturation and state:

> *'Beginning with the development of a novel artefact. Knowledge then becomes more abstract and more general and the web of knowledge becomes more comprehensive with clearer delimitation of boundaries. Special conditions that might need variation in the theory are discovered. Pushing the knowledge beyond prior domain constraints and into new fields means that the boundaries of a theory receive more testing and more support. These advances mean greater understanding of when a theory works and why and more evidence for a theory as a whole. Thus, the field (both problem and solution domains) is considered more mature.'* (Gregor & Hevner, 2013, pg 339)

Section 6.3 presents the evaluation of the eNEWS V2.0 chart with the instantiated framework for REVIEWS V0.1 using a narrative text to demonstrate the results. From an overall perspective, it was observed that the application of the framework to V1.0 of the eNEWS chart had a significant positive impact on the usefulness of the chart. The analysis presented in section 6.3 also demonstrated how some specific design features had the predicted impact on specific tasks performed during the information processing phase of clinical reasoning. However, as presented in section 6.3.5 there were a number of specific design features that interviewees did not describe as having a positive impact on the usefulness of eNEWS V2.0. The development of a design theory or a grand theory requires that the boundaries of a theory are to be tested and explained and while this thesis pushes the findings of the evaluation, ultimately there are design principles that need to be further tested in order to formalise the impact they have on the problem system. As such, while it can be stated that the analysis of the evaluation presented in section 6.3 represents the initial phases of moving the framework from a level 2 to a level 3 DSR output, it cannot yet be categorically classified as a level 3 output.

The framework demonstrates a significant contribution to observation chart design literature. While the framework has been designed specifically for electronic observation charts many of the rules may also be appropriated for the design of paper-based charts. The framework makes explicit many design principles that would previously have been implicitly known by observation chart designers. The

framework for REVIEWS represents a coherent and comprehensive set of prescriptive statements that can be applied to the design of observation charts, which if appropriately instantiated will positively impact the information processing tasks performed by nurses during clinical reasoning. Furthermore, the framework represents a contribution to a small pool of observation chart literature. At the time of performing the literature review for this thesis a small pool of observation chart design literature existed. This pool could be traced to the research group associated with the report prepared for the Australian Commission on Safety and Quality in Health Care (Horswill, Preece, Hill, Christofidis, Karamatic, et al., 2010). To the best knowledge of the author; no other significant research efforts exist that focus on formalising design principles/features for observation charts. The research presented in this thesis builds on the existing work and the framework represents a logical next step for this research.

As previously noted, the framework is designed specifically for electronic observation charts. This also represents a major contribution to literature as, to the best knowledge of the author; it is the only research effort thus far that has focused on formalising a set of design principles that can guide the design of an electronic medical interface. While the framework was designed for a specific class of artefact (i.e. electronic observation charts) it is likely that the framework could be applied or adapted to suit the design of an electronic interface that presents patient data over a period of time. As such, there is a great opportunity for the design principles that constitute the framework to be adapted and re-appropriated in differing context.

7.4.2. Positioning The Framework for REVIEWS as a DSR Knowledge Contribution

Having established the type of DSR contribution the Framework for REVIEWS represents in section 7.4.1, it is useful to position REVIEWS in terms of the solution maturity and the application domain maturity. Gregor & Hevner, (2013) observe that formalising the knowledge contribution of a DSR artefact can be difficult due to the artefact itself, the maturity of existing literature, the nature of the interested parties and the pertinent publication outlets. Furthermore, they state that establishing what is new or novel and the maturity of the "new" knowledge exists on a spectrum. In an effort to guide researcher's to understand the maturity of their DSR contribution,

Gregor & Hevner developed the *DSR Knowledge Contribution Framework (*Figure 7.4). Each quadrant in the framework presents a description of the contribution type and whether the contribution type presents a research opportunity and a knowledge contribution.

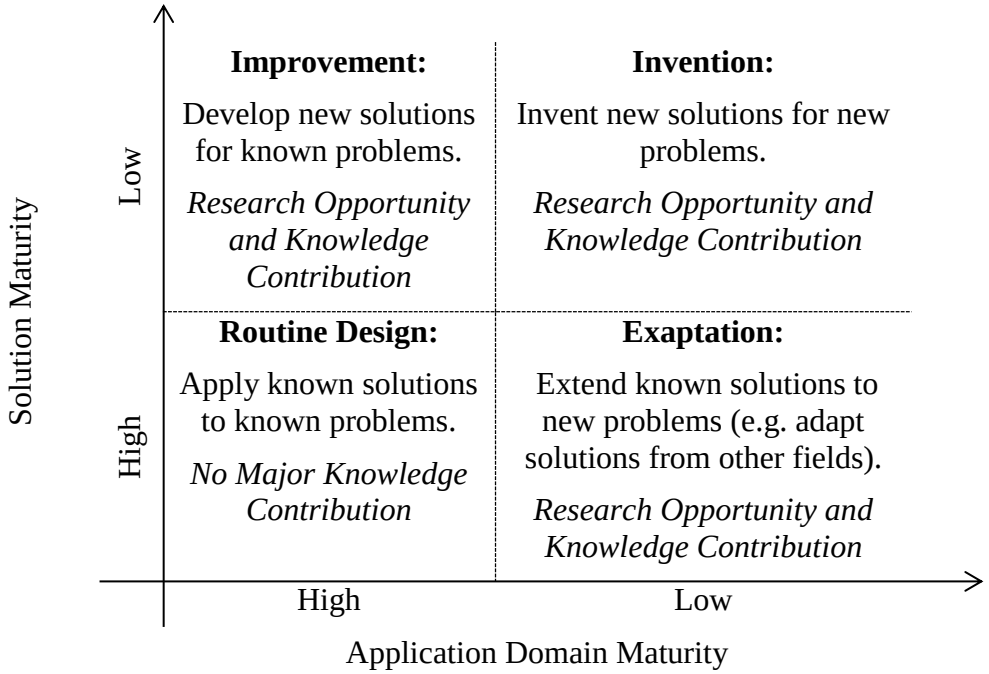


Figure 7.4. DSR Knowledge Contribution Framework. Source: (Gregor & Hevner, 2013)

As discusses in section 7.4.1, the Framework for REVIEWS constitutes a set of prescriptive guidelines which can be applied to the design of an electronic observation chart to support nurses when processing information presented on the chart. Prior to discussing the novelty of REVIEWS as a *'solution'*, there is first a necessity to discuss the nature of the problem that REVIEWS seeks to resolve.

Design research typically employs a *design-build-evaluation* approach where a problem is identified and precisely articulated, an artefact is designed to address the problem and finally the artefact is evaluated to see whether it has addressed the problem (Peffers et al., 2008; Venable, 2006a). In chapter 5 the *problem system* and *required change in the problem system* for REVIEWS was identified as:

Problem system	• Initial assessment for acute illness, • Continuous monitoring of patient's during their hospital stay and • Early identification of potential clinical deterioration in patients.
Required change in problem system	• Improve how data is presented in order to: o *Provide easier recognition of patient data* o *Aid identification of abnormal clinical parameters*

While this problem and the changes required are broadly consistent with previous observation chart design approaches (Preece et al., 2009; Royal College of Physicians, 2012), REVIEWS differs in terms of how it has addressed the problem system. The design of REVIEWS is contingent on a sophisticated in-depth understanding of the nature of the problem system. A criticism of the existing observation chart design literature presented in chapter 2 was that there was no clear connection between the problem and the theory employed to address the problem. In the case of REVIEWS an in-depth knowledge discovery process is conducted in order to fully understand the problem system and to search for useful theoretical knowledge that can contribute towards the design of the artefact. This can be seen in the evaluation of existing observation charts presented in chapter 4 and the literature search presented in chapter 5. This process helped to establish the problems that HCPs face when using an observation chart is one of *information processing,* i.e. whether the HCP can understand the information presented on the chart. This finding presented in chapter 5 allows for an expanded understanding of the problem system and therefore allowed REVIEWS to resolve a new problem that had not previously been considered in other research.

Having discussed the fact that REVIEWS has been designed to address a previously unconsidered problem, it is now useful to consider the nature of the solution and whether REVIEWS can be thought to be novel. Gregor & Hevner accept that *nothing is really "new"*, and that all knowledge typically builds on previous ideas or is made up of several other combined ideas, as such it is useful to consider whether the

Framework for REVIEWS is *"new to the world"*. In order to establish whether REVIEWS is something new, it is useful to first reflect on existing observation chart design literature.

From the review of existing observation chart design literature presented in chapter 2, it can be observed that the existing approach to observation chart design was sub-optimal in terms of formalising a logical, coherent and comprehensive set of design principles for the design of observation charts. The existing literature was criticised as it did not present a transparent design process and it was not clear how the design choices were made in order to affect a particular problem. As such, there was a necessity for REVIEWS to be designed in a transparent way where adequate theoretical knowledge is utilised to help resolve a precisely articulated problem. REVIEWS achieved this through adapting theoretical knowledge that emerged from cognitive fit, sense making and semiology of graphics literature. While it must be acknowledged that the framework for REVIEWS leveraged the work of Baker et al., 2009; Benner, 1994; Bertin, 1983; Fekete et al., 1973; Parsonson & Baer, 1978; Spelke, 1990; Spriggs et al., 2014; Vessey, 1991; Weick et al., 2005, REVIEWS represents a novel artefact in terms of its unique synthesis and articulation of this literature. As such it is reasonable to state that the Framework for REVIEWS a novel artefact.

The observations made thus far in this section suggest that REVIEWS represents a new solution to a new problem. It is reasonable to state that REVIEWS can be classified as an *invention*. This implies that REVIEWS is a recognisably novel artefact, and that significant effort has been made to formalise an understanding of a problem space with ill-defined criteria for which few solutions currently exist.

7.4.3. An Evaluation Approach that Connects Task with Theory

A key benefit of employing a DSR approach for designing an artefact is the emphasis placed on using scientific methods to rigorously evaluate the utility of the artefact (A. R. Hevner, 2007). This evaluation is based on the assumption that the artefact has been designed in a purposeful manner, i.e. that the artefact impacts the problem system in the required way. The evaluating method should therefore reflect this. A criticism that emerged of existing observation chart design literature is that the evaluation method created a disconnect between task and theory. The evaluation

method analysed the impact that specific design features had on the speed and accuracy by which nurses could identify abnormal vital signs. While this is an important task performed by nurses when using an observation chart, it does not fully represent the breadth of tasks performed by nurses when using an observation chart. As such, there was a necessity for this research to design an evaluation method that adequately reflected the breadth of tasks performed by nurses when using an observation chart.

Considering this, the evaluation method employed by this research leveraged the design knowledge discovered in the Irish HSE's NEWS chart. This discovery process established that when a nurse performs information processing tasks associated with clinical reasoning while using an observation chart, with the most important tasks being performed including: *initial interpretation of information, discriminating between more and less important information, identifying relationships in information, matching current situation to previous analogous situations for current or previous patients* and *predicting outcomes based on the information* (Levett-Jones et al., 2010). These tasks have been identified as the most important tasks performed by nurses when using an observation chart. An evaluation method should evaluate the artefact with regard to its capacity to facilitate these tasks. In the case of the research presented in this thesis, a semi-structured interview method was designed to comparatively evaluate how useful specific observation charts are in respect to facilitating each of the information processing tasks identified.

This particular evaluation method underwent a significant amount of revision prior to the final implementation. A two-phase interview refinement process was conducted based on a pre-test and pilot of the interviews with a representative sample of four participants. This phase provided some insight into how nurses use the NEWS Chart to assist their clinical reasoning processes, as well as allowing the interviewer to become more practised in speaking with health professionals. Furthermore this process allowed for nurses to give feedback on the information processing tasks identified in literature and confirmed the applicability of the particular tasks identified in literature to tasks they perform when using observation charts. As such, the evaluation method used in this research represents a contribution

to any literature that seeks to evaluate observation chart design. It demonstrates the importance of an evaluation method that connects task with theory and provides a template by which future observation chart designs can be evaluated.

7.4.4. Applications of this Research for Practice and Paths for Academia-Practice Innovation Partnerships

Venable, (2006, pg. 184) suggests that Design Science Research (DSR) represents *an excellent opportunity for the IS field to increase its relevance to practice in practice* and posits that DSR should be guided by both practical *business needs* and relevant *applicable knowledge* (design knowledge). Peffers et al., (2008) make a similar observation stating that DSR typically meets the needs of either a practice or research need. The research presented in this thesis has focused on improving the design of an observation chart used by nurses in a hospital setting and has leveraged explicit theoretical knowledge and implicit experiential knowledge in order to do so. Considering that the nature of this research has focused on a practical problem it is logical that the research would also produce knowledge with application to practice.

Section 7.4.1 discussed the importance of the framework for REVIEWS as an output of DSR research and how the framework represents an important contribution to observation chart design literature. Again, the very nature of observation chart design literature is concerned with designing an artefact (i.e. the observation chart) that provides support for a specified problem system (i.e. tasks performed when using an observation chart). The existing pool of observation chart design literature is small with the principal source of literature emerging from a group who prepared a report for with the Australian Commission for Quality and Safety in Health Care and Queensland Health (Horswill, Preece, Hill, Christofidis, Karamatic, et al., 2010). The impact of their literature is evident in its application in practice, with the design literature for the Irish HSE's NEWS chart citing their work as having a significant impact on the design of the NEWS chart. Further evidence of the impact can be seen with the group being cited by the Royal College of Physicians for the design of the NEWS chart used in the United Kingdom's National Health Service (NHS) (Royal College of Physicians, 2012). As such, if adequately communicated with groups concerned with the design of an electronic observation chart, the framework can serve as an important contribution to the design of observation charts. The

framework can also act as a template from which to improve the design of both existing electronic observation charts and it can influence the design of future observation charts.

Section 7.4.1 also discussed how the practical application of the framework for REVIEWS to V1.0 of the eNEWS chart resulted in in V2.0 of the eNEWS chart. This also represents an important contribution to practice. The goal of DSR is to design artefacts that resolve problems, with DSR typically employing an iterative approach to the design of an artefact in order to improve on the design of the artefact (A. R. Hevner, 2007; Järvinen, 2007). In the case of this research it can be stated that the eNEWS V2.0 chart was considered to be significantly more useful than the eNEWS V1.0 chart. This is demonstrated in the evaluation of the charts presented in chapter 6. The introduction of this chart to a practical setting will provide superior support for nurses using the chart for the tasks performed during the information processing phase of the clinical reasoning process. Furthermore, there is potential for additional evaluation of the eNEWS V2.0 chart and it can provide a platform for future iterative design.

The development of the approach for discovering design knowledge embedded in situated artefacts (presented in section 3.4.1) also represents a useful contribution to increasing the relevance of DSR to practice. As noted in section 7.4.1 previous DSR has presented approaches for the design of novel artefacts to resolve problems. However, not all problems require or can justify the design and development of an entirely new artefact or instantiation in order to resolve a problem. It is common for a development project to be restrained by budget and may want to build on an existing artefact rather than start anew. The approach presented in this thesis can be used to allow for iteration on such situated artefacts. This approach can be used in academia or practice equally and therefore represents a useful contribution to practice. There is significant potential for refining the theoretical aspects of this approach through using the approach in industrial settings.

7.5. Limitations of the Research

This chapter has thus far presented a summary of the principle findings from this study, as well as the contributions of these findings to relevant academic communities and interested practice based parties. While the ultimate objective of

the research has been met there is a need to address some inherent limitations of the research. The limitations presented also represent an opportunity to expand on the research, to strengthen and further explore opportunities for the research. The evaluation method presented in this study used a semi-structured interview method to evaluate how nurses perceived respective charts to support specific information processing tasks during clinical reasoning. In total, there are four key limitations that can be attributed to the evaluation method employed in this study.

The first of these limitations related to nurses understanding of the information processing tasks. Prior to conducting the interviews a refinement process established that nurses did not have an accurate understanding of the information-processing tasks, this was alleviated by using practical examples of each task to help illustrate them. It was established that presenting examples was useful, however, when conducting the interviews it became evident that not all nurses performed all of the information processing tasks. In cases where nurses did not have experience of performing a task the question was skipped and the Likert score was not recorded for the interviewee. During the first evaluation phase, 1 interviewee said they did not perform *situation matching* and in the second evaluation phase 1 interviewee also said they did not perform *situation matching*. In the third evaluation phase there were no tasks that nurses felt they did not perform. A possible explanation for this finding is that *situation matching* was not a task performed by some nurses. It is also likely that it is a task that nurses perform implicitly. While it is not possible to formally establish why this task was not knowingly performed by all nurses, it represents a fundamental issue with qualitative data collection methods. That is to say that qualitative data collection methods lack the control of quantitative methods.

The second potential limitation of the evaluation method chosen is that the analysis of the data may have been subjectively interpreted by different individuals. While the Likert scales were used as a form of sanity check to ensure that the analysis of the findings were consistent with how useful the nurses perceived the respective charts to be, there is still potential for misinterpretation of the results. While this research represents an important step in the design of electronic observation charts, the research demonstrates the importance of linking information processing tasks performed during clinical reasoning with the design of the observation chart. Future

research may choose to design specific software features that can help to support specific information processing tasks. In order to measure the impact of these features it may be necessary to establish more objective measures for evaluating the impact of specific features.

A third limitation that emerges from the nature of the evaluation method and the case study chosen arises from the fact that the framework for REVIEWS is being applied to a situated artefact. While this situation led to the useful development of the approach for discovering design knowledge embedded in situated artefacts, it also means that many of the principles that constitute the framework were already adequately instantiated in the eNEWS V1.0 chart. In an ideal scenario it would be preferable to be able to instantiate each design principle individually. This would allow for assessment of their impact on specific information processing tasks. However, due to the nature of the case used for this study this was not possible. A potential opportunity for future research may seek to address this limitation by creating a new instantiation that can be used to evaluate the impact of each specific design principle.

A fourth limitation that emerges from reflection on the evaluation method is the number of sites the evaluation was performed in. While the interview respondents volunteered randomly for the interview process there was some overlap in the nurses interviewed during each evaluation phase. While the results that emerge from the interview process appear to be consistent and therefore generalisable, future research may employ more sites for evaluation of the observation charts.

7.6. Concluding Remarks

Observation charts represent a vital component of information systems for communicating patient health information to healthcare professionals. At a time when healthcare data is becoming increasingly digitised and the means of presenting patient health information is changing from paper-based to electronic interfaces, it is necessary for the designer of electronic observation charts to adequately align the design of the interface with the tasks they are designed to support. The research presented in this thesis builds on existing observation chart design literature and focuses on supporting the information processing phase of the clinical reasoning process.

The framework for REVIEWS V1.0 represents the principle contribution of this research. This research employed a Design Science Research (DSR) approach to structure the process of discovering, synthesising, applying and evaluating design knowledge with the goal of designing a better electronic observation chart. V1.0 of the framework embodies the most mature iteration of this formalised knowledge. This approach was necessary as existing observation chart design research did not present a coherent and transparent set of design guidelines on which to base the design of an electronic medical observation chart. REVIEWS V1.0 itself consists of a set of 24 prescriptive design principles to guide the design of electronic observation charts. The design principles are presented in a structured coherent manner with implied technological rules, and the process for identifying and selecting these principles is transparently presented in this study. Furthermore, the evaluation of the framework as presented in chapter 6 demonstrates the significant positive impact of instantiating the framework. It can therefore be said that the framework for REVIEWS represents a contribution to observation chart design literature.

While the framework represents the primary output of this research, the research also made other significant useful contributions to both academia and practice. As discussed in section 7.4, this research also formalised an evaluation approach for establishing the perceived utility of observation charts in terms of supporting the information processing tasks performed by nurses during the clinical reasoning process. It was necessary to formalise this approach in order to establish the comparative utility of the respective observation charts presented in this research. Existing observation chart design literature employs quantitative approaches that measure the speed and accuracy by which nurses can detect abnormalities in patient vital sign recordings. While this approach is useful it does not adequately capture the breadth of tasks performed by nurses when using an observation chart to understand a patient's current situation. As such, there was a necessity to design an evaluation approach that connects task with theory. This evaluation approach leveraged theoretical knowledge pertaining to sense making, cognitive fit and clinical reasoning literature as well as practical knowledge gathered during pre-test and pilot interviews. The approach presented in this research contributes to literature as it represents a deeper questioning of methodological issues than existed in previous

research and it can act as a template on which to base future observation chart evaluation.

eNEWS V2.0 represents the most mature iteration of the electronic observation chart developed for this research and it also represents a significant contribution to practice. DSR is concerned with scientifically designing artefacts that resolve real-world problems. The comparative evaluation of the three respective observation charts presented in this research (paper-based NEWS chart, electronically generated eNEWS V1.0 and eNEWS V2.0) demonstrated that nurses perceived the eNEWS V2.0 chart to be considerably more useful than both the paper-based NEWS chart and V1.0 of the eNEWS chart. eNEWS has been designed to be used in hospitals, the application has potential beyond the observation chart to improve the speed and accuracy by which vital sign information is captured as well as providing a platform for easily collecting and analysing patient vital sign information. In order for the application to be accepted by users there is a necessity for the user to perceive value in the application. The observation chart produced by the application represents the primary interface between the user and the information, and by designing an observation chart that is considered to be significantly more useful than both the paper-based charts already in use in hospitals and V1.0 of the electronic observation chart, the likelihood of users adopting the application is significantly improved.

Finally there is also significant opportunity for future research. The framework for REVIEWS presented in this thesis represents a mature version of the framework, however there is also potential for future application of the framework in differing contexts and for further exploration of the theoretical base. This can allow for improving the framework and increasing the generalisability of the design theory. From a practical perspective further industrial application for the framework for REVIEWS can be also be established where there is need to design early warning systems.

Appendix 1: Early Warning Score.

Source: Training Manual for The National Early Warning Score and associated Education Programme: Compass 'Pointing you in the right direction' (Avard et al., 2011, pg. 8 - 13).

(Text relating to other section in training manual omitted)

Early Warning Score

A "vital" sign is a sign that pertains to life, without which life would not exist.

Vital signs constitute pulse, blood pressure, respiratory rate and temperature. Derangements in pulse and blood pressure measurements can reflect an increased threat to life so can be considered a "vital sign".

Derangements in pulse, blood pressure, respiratory rate and temperature measurements reflect an increased risk of death. It is important to detect, observe and record these vital signs early and deliver timely treatment not only to normalise these signs, but also to decrease the risk of the patient dying.

Background

An Early Warning Score (EWS) is a bedside score and track and trigger system which nursing staff calculate from the vital signs recorded and aims to indicate early signs of a patient's deterioration.

It is a valuable additional tool to facilitate detection of a deteriorating patient, particularly in acute hospital wards where patients are often quite unwell and there may be many inexperienced staff. Vital signs only include Pulse, Blood Pressure, Respiratory Rate and Temperature; however, the ViEWS takes into account other observations as well.

The Early Warning Score (using ViEWS parameters) considers all the patient's recorded observations together, not just a single observation in isolation. It includes pulse, blood pressure, respiratory rate, temperature, oxygen saturation, FiO2

(inspired O2) and AVPU (Alert, response to Voice, response to Pain, Unresponsive) score (see Patient Observation Chart).

Trigger Score A score of 3 in any single parameter is a trigger point for action.

A score of 2 for Heart Rate ≤ 40 (Bradycardia) is a trigger point for action.

A total score of 3 is a trigger point for action, with escalated notification at 4-6 & 7 (see Escalation Protocol Flow Chart).

Text Box 1: Trigger Score

The EWS policy includes:

(Individual hospitals must review this and adapt as appropriate)

- Direction to nurses as to what level of doctor needs to be notified, based on the EWS score.
- Direction for nurses on the frequency of vital sign observation measurement once a trigger score is reached.

EWS is beneficial as:

- It provides a point in time for communicating the changes in a patient's vital signs and observations and empowers nurses and junior doctors to take appropriate action.
- **It does not replace clinical judgement when staff are concerned about a patient** (see Text Box 2).
- It assists doctors in prioritising the management of their patients.
- Prompts more timely medical review and treatment of patients as it has an inbuilt escalation policy if the patient has not been reviewed within the required time frame.
- Does not replace calling an Emergency Response System (ERS).

1. **EWS does NOT replace calling the cardiac arrest team in the event of collapsed adult with suspected no pulse and/or no breathing.**
2. **EWS does not replace calling the ERS.**
3. **EWS does not replace contacting the registrar/consultant for immediate review of any patient that the health care professional is seriously worried about, including a patient with a sudden fall in level of consciousness, fall of GCS > 2 (where this score is in use), repeated or prolonged seizures or threatened airway.**

Text Box 2: EWS

NOTE: The Emergency Response System (ERS) must be identified in each acute hospital for daytime, out of hours, weekends etc. as appropriate to their local hospital model. See further information on hospital models in Acute Medicine Programme document on www.hse.ie.

Adult EWS Calculation

To obtain the total EWS:

1) Record a full set of vital sign observations on the patient

2) Each individual observation is scored according to the criteria outlined below (Table 1)

3) Total the score for each observation to achieve a total score.

Table 1: Adult Early Warning Score for each variable

Early Warning Score – ViEWS - Key							
SCORE	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Respiratory Rate (bpm)	≤ 8		9 – 11	12 – 20		21 – 24	≥ 25
SpO2 (%)	≤ 91	92 – 93	94 – 95	≥ 96			
Inspired O2 (FiO2)				Air			Any O2
Systolic BP (mmHg)	≤ 90	91 – 100	101 – 110	111 – 249	≥ 250		
Heart Rate (BPM)		≤ 40	41 – 50	51 – 90	91 – 110	111 – 130	
AVPU/CNS Response				Alert (A)			Voice (V), Pain (P), Unresponsive (U)
Temp (°C)	≤ 35.0		35.1 – 36.0	36.1 – 38.0	38.1 – 39.0	≥ 39.1	

Note: Where systolic blood pressure is ≥ 200mmHg, request Doctor to review.

Track and Trigger procedures

If any single parameter scores 3 or the total EWS reaches a trigger score of 3, the activation protocol must be initiated (Text Box 3).

If the total EWS reaches a trigger score of 4-6 & 7, escalated notification must be initiated (see Escalation Protocol Flow Chart, Figure 1):

A. Increase Frequency of Vital Sign Observations

When the total EWS score is **2**, the nurse in charge must be notified and observations increased as per Escalation Protocol. The minimum monitoring recommended is 6 hourly. The frequency of observations may be increased at any stage by the nurse.

With improvement of the patient's condition, the Escalation Protocol may be stepped down as appropriate and documented in the management plan.

When the total EWS score is **3**, the nurse in charge and the Team/On-call SHO must be notified and observations increased as per Escalation Protocol.

Total EWS Trigger Point - Score of 3:

Notify Nurse in charge and Team/On-Call SHO, 4 hourly observations, SHO to review patient within 1 hour.

Text Box 3: Activation Protocol

B. Communicate Score Appropriately

The nurse must notify the CNM/nurse in charge, when a patient reaches a total score of 2 (Text Box 4).

The nurse must notify the nurse in charge and the relevant medical personnel, depending on the EWS as outlined in the Escalation Protocol flow chart (Figure 1).

At the time of a patient reaching a score of 2, the nurse must notify the CNM/Nurse in charge. If the patient reaches a score of 3 or above, the nurse must always notify the nurse in charge and the relevant medical personnel.

Text Box 4: CNM Notification

Resuscitation status should be established and documented in the patient's notes by the primary medical team.

National Early Warning Score Escalation Protocol Flow Chart

Note: In the event of respiratory or cardiac arrest activate the cardiac arrest system. If EWS score is 3 in any single parameter or AVPU score is 3 or GCS (where this score is in use) falls > 2 points contact doctor for immediate review and follow escalation plan.

Figure 1: EWS Escalation Protocol

Escalation Protocol Flow Chart

Total Score	Minimum Observation Frequency	ALERT	RESPONSE
1	12 Hourly	Nurse in charge	Nurse in charge to review if new score1
2	6 Hourly	Nurse in charge	Nurse in charge to review
3	4 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within 1 hour
4-6	1 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within ½ hour 2. If no response to treatment within 1 hour contact Registrar 3. Consider continuous patient monitoring 4. Consider transfer to higher level of care
≥ 7	½ Hourly	Nurse in charge & Team/On-Call Registrar Inform Team/On-Call Consultant	1. Registrar to review immediately 2. Continuous patient monitoring recommended 3. Plan to transfer to higher level of care 4. Activate Emergency Response System (ERS) *(as appropriate to hospital model)*
Note: Single Score triggers			
Score of 2 HR ≤ 40 (Bradycardia)	½ Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review immediately
*Score of 3 in any single parameter	½ Hourly or as indicated by patient's condition	Nurse in charge & Team/On-call SHO	1. SHO to review immediately 2. If no response to treatment or still concerned contact Registrar 3. Consider activating ERS
*In certain circumstances a score of 3 in a single parameter may not require ½ hourly observations i.e. some patients on O_2. • When communicating patients score inform relevant personnel if patient is charted for supplemental oxygen e.g. post-op. • Document all communication and management plans at each escalation point in medical and nursing notes. • Escalation protocol may be stepped down as appropriate and documented in management plan.			
IMPORTANT: 1. If response is not carried out as above CNM/Nurse in charge must contact the Registrar or Consultant. 2. If you are concerned about a patient escalate care regardless of score.			

Adapted from CJUH/KU chart

Escort required out of ward area: consider expertise of personnel and equipment required for safe transport.

Where a patient is being continuously monitored using electronic technology, a full set of vital signs data must be documented on the observation chart, as per Escalation Protocol.

Summary EWS Adult

Trigger score: A score of 2 for Heart Rate ≤ 40 (Bradycardia) is a trigger point for action. A score of 3 in any single parameter or total EWS of 3 is the trigger point for action, with escalated notification required at EWS of 4-6 and 7 or if the patient is not improving.

1. **EWS does NOT replace calling the cardiac arrest team in the event of collapsed adult with suspected no pulse and/or no breathing.**
2. **EWS does not replace calling the ERS as appropriate to local hospital model.**
3. **EWS does not replace contacting the registrar/consultant for immediate review of any patient that staff are concerned about, including those who experience a sudden fall in level of consciousness, fall of GCS>2, repeated or prolonged seizures or threatened airway.**

The Early Warning Score guides the Escalation Protocol.

The Early Warning Score does not replace clinical judgement when staff are concerned about a patient

Always remember that you must consider all the clinical observations when assessing a patient and not just a single parameter in isolation.

Note: The scoring parameters for the physiological signs identified in the Nationally agreed Early Warning Score (ViEWS) in Table 1, must be strictly adhered to.

Appendix 2: Publication Centric Information Processing Tasks Matrix (1987 – 2013)

***A column marked with a 1 indicates that the author identifies the task as one performed during information processing**

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
How Expert Nurses Use Intuition	(Benner & Tanner, 1987)	International journal of nursing terminologies and classifications	1987	1	1	1	1	1	0	0	1	0
Expert nurses' clinical reasoning under uncertainty: representation, structure and process.	(Fonteyn & Grobe, 1992)	Proceedings of the Annual Symposium on Computer Application in Medical Care. American Medical Informatics Association	1992	1	1	1	1	1	0	0	0	0
Diagnostic Process and Decision Making A Literature Review in Nursing : A Literature Review	(Hamers, 1994)	Journal of professional nursing : official journal of the American Association of Colleges of Nursing	1994	1	1	1	1	0	0	0	0	0

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
Some surprising similarities in the clinical reasoning of 'expert' and 'novice' orthopaedic nurses: report of a study using verbal protocols and protocol analyses.	(Greenwood & King, 1995)	Journal of advanced nursing	1995	0	0	0	1	0	0	0	0	0
Researching children's nurses' clinical judgements about assessment data	(Mason & Webb, 1997)	Clinical Effectiveness in Nursing	1997	1	1	0	1	0	0	0	0	0
Strategies for teaching clinical decision-making	(Boney & Baker, 1997)	Nurse education today	1997	1	1	1	1	1	0	1	0	0
Decision making by emergency nurses in triage assessments.	(J Cioffi & May, 1998)	Accident and emergency nursing	1998	0	1	1	1	0	0	0	0	0
Diagnostic reasoning processes using patient simulation in different learning environments.	(Wong & Chung, 2002)	Journal of clinical nursing	2002	0	1	0	1	0	0	0	0	0

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
Clinical Reasoning in Experienced Nurses	(Simmons, Lanuza, Fonteyn, Hicks, & Holm, 2003)	Western Journal of Nursing Research	2003	1	0	0	1	1	1	0	1	1
Thinking in Clinical Nursing Practice: A Study of Critical Care Nurses' Thinking Applying the Think-Aloud, Protocol Analysis Method	(Han et al., 2007)	Asian Nursing Research	2007	1	1	1	1	0	0	1	0	1
Clinical reasoning and its application to nursing: concepts and research studies.	(Banning, 2008a)	Nurse education in practice	2008	1	0	0	1	0	0	0	1	1
The think aloud approach as an educational tool to develop and assess clinical reasoning in undergraduate students.	(Banning, 2008b)	Nurse education today	2008	0	1	1	1	0	0	0	0	1

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
A comparison of novice and expert nurses' cue collection during clinical decision-making: verbal protocol analysis.	(K. a Hoffman et al., 2009)	International journal of nursing studies	2009	1	1	1	1	1	0	0	0	0
Determinants of the accuracy of nursing diagnoses: influence of ready knowledge, knowledge sources, disposition toward critical thinking and reasoning skills.	(Paans, Sermeus, Nieweg, & van der Schans, 2010)	Journal of professional nursing : official journal of the American Association of Colleges of Nursing	2010	0	1	1	1	0	0	0	0	0
Using the Situated Clinical Decision-Making framework to guide analysis of nurses' clinical decision-making.	(Gillespie, 2010)	Nurse education in practice	2010	1	0	1	1	0	0	1	1	0

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
Final-year nursing students' ability to assess, detect and act on clinical cues of deterioration in a simulated environment.	(Endacott et al., 2010)	Journal of advanced nursing	2010	1	1	0	1	0	0	0	1	0
The 'five rights' of clinical reasoning: an educational model to enhance nursing students' ability to identify and manage clinically 'at risk' patients.	(Levett-Jones et al., 2010)	Nurse education today	2010	1	1	1	1	1	1	0	0	1
A review of the literature: midwifery decision-making and birth.	(Jefford, Fahy, & Sundin, 2010)	Women and birth : journal of the Australian College of Midwives	2010	1	1	1	1	1	0	0	0	0

Paper Title	Reference	Journal / Conference	Year	Pattern Recognition	Interpret Cues	Matching to previous situations	Relating Information	Discarding Irrelevant Data	Search Missing Information	Assess validity of information	Judging Value of Information	Provide Explanations
The design and implementation of an Interactive Computerised Decision Support Framework (ICDSF) as a strategy to improve nursing students' clinical reasoning skills.	(K. Hoffman et al., 2011)	Nurse education today	2011	1	1	1	1	1	0	0	0	0
Critical thinking in clinical nurse education: application of Paul's model of critical thinking.	(Andrea Sullivan & Sullivan, 2012)	Nurse education in practice	2012	0	1	0	1	0	1	0	1	1
Diagnostic reasoning in osteopathy – A qualitative study	(Thomson, Petty, & Moore, 2013)	International Journal of Osteopathic Medicine	2013	1	1	1	1	0	1	0	0	1
The clinical viva: an assessment of clinical thinking.	(Roberts, 2013)	Nurse education today	2013	0	1	1	1	1	0	0	0	1
Total				**23**	**24**	**23**	**22**	**12**	**5**	**4**	**8**	**8**

Appendix 3: Author Centric Table of Design Science Approaches (1988 – 2011)

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
(Simon, 1988)	Satisfying specified constraints.	N/A	N/A	N/A	N/A	With satisficing goals the sought-for worlds are seldom unique.
(Nunamaker-Jr et al., 1990)	A clear definition of the research problem provides a focus for the research throughout the development process.	Design involves understanding of the studied domain, the application of relevant scientific and technical knowledge, the creation of various alternatives and the synthesis and evaluation of proposed alternative solutions.			Implementation of a system is used to demonstrate the feasibility of the design and the usability of the functionalities of a system development research project.	Observe and evaluate the system. Once the system is built, researchers can test its performance and usability as stated in the requirement definition phase, as well as observe its impacts on individuals, groups or organisations. The test results should be interpreted and analysed based on the conceptual framework and the requirements of the system defined in the earlier stages

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
(Walls et al., 1992)	Generalised set of requirements. "The first component of a design theory dealing with the product of design is a set of meta-requirements which describe the class of goals to which the theory applies. Design theory does not address a single problem but a class of problems.	Kernel theories from natural or social sciences which govern design requirements.	Two key elements in an explanatory design theory, the requirements and the components and their embodies relationships that explain the situation		Design method which describes procedure(s) for artefact construction.	Testable design hypotheses which can be used to verify whether the meta-design satisfies the meta-requirements
(Markus et al., 2002)	Based on Walls version of theorizing in design science	N/A	N/A	Design Theory Components: (1) a set of user requirements derived from kernel theory, (2) principles governing the development process, (3) principles governing the design of the system	N/A	N/A

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
(A. R. Hevner et al., 2004)	Problem Relevance - object of design science research is to develop technology-based solutions to important and relevant business problems. Research Rigor…	Design as a search process - the search for an effective artefact requires utilising available means to reach desired ends while satisfying laws in the problem environment…. Research Rigor	Communication of research - must be presented effectively both to technology-orientated as well as management-orientated audiences…. Research Rigor… Foundations - Constructs, Models	Design as an artefact - construct / model / method. Research Rigor… Foundations - Theories, frameworks, instruments, methods	Design as an artefact - instantiation… Research Rigor… Foundations instantiations	Design Evaluation - The utility, quality and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods… Methodologies - Data analysis techniques, formalisms, measures, validation criteria…. Justify/Evaluate - Analytical, case study, experimental, field study, simulation
(Walls et al., 2004)	Meta-requirements and meta-design, which deal with a class of information systems rather than a specific instance of one.	N/A	N/A	N/A	N/A	N/A
(Goldkuhl, 2004)	N/A	Explanatory grounding means that action rules and other practical knowledge are given justification in general explanatory theories. Those theories correspond	N/A	Design theories consist of knowledge of practical character; i.e. for practical purposes. The knowledge aims at contributing to design processes….	N/A	The justification of design theories can be made in relation to: 1) The design theory itself (internal grounding), 2) empirical observations (external grounding), 2) other knowledge of theoretical character (theoretical grounding)

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
		to "kernel theories"… As opposed to Walls et al (1992) I do not conceive kernel theories to be indispensable arts of design theories.				
(Gregor & Jones, 2007)	Purpose and scope. "What the system is for", the set of meta-requirements or goals that specifies the type of artefact to which the theory applies and in conjunction also defines the scope or boundaries or the theory.	Justificatory Knowledge: The underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design. (kernel theories)	Constructs: Representations of the entities of interest in the theory	The distinguishing attributes of theories for design and action is that they focus on 'how to do something'. They give explicit prescriptions on how to design something	Principles of implementation: A description of processes for implementing the theory (either product or method) in specific contexts. Expository instantiation. A physical implementation of the artefact that can assist in representing the theory both as an expository device and for purposes of testing	Testable propositions: Truth statements about the Design Theory
(Peffers et al., 2008)	Problem Identification and motivation. Define the specific research problem and justify the value of a solution…. Define the objective for a solution. Infer the		N/A	Design and Development. Create the artefact. Such artefacts are potentially constructs, models, methods or instantiations (each defined broadly). This activity includes determining the		Evaluation. Observe and measure how well the artefact supports a solution to the problem. This activity involves

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
	objectives of a solution from the problem definition and knowledge of what is possible and feasible			artefacts desired functionality and its architecture and then creating the actual artefact.		comparing the objectives of the solution to the problem.
(Kuechler & Vaishnavi, 2008)	Awareness of the problem. An awareness of an interesting problem can come from multiple sources: new developments in practice or in a reference discipline. Reading in an allied discipline may also provide the opportunity for application of new findings to the researcher's field.	A tentative design and possible an artefact is developed based on human creativity.			Development. The tentative design if further developed and implemented in this phase. Elaboration of the tentative design into complete design requires creative effort.	Evaluation. Once constructed, the artefact is evaluated according to criteria that are always implicit and frequently made explicit in the proposal.

	Utility Requirements	Kernel Knowledge	Explanatory Model	Design Theory	The Instantiation	Utilitarian Evaluation
(Baskerville & Pries-Heje, 2010)	The definitions of general requirements and general components must be circular. Requirements specify the reasons for components. Components are justified by requirements.	We could have kept the notion of kernel theories. However, it is unclear exactly what kernel theories contribute and why such separate theories should be integrated with explanatory theories.	N/A	Two types of design theory. Design practice theory, prescribes in a practical way how to design something. The second type of design theory prescribes principles that relate requirements to an incomplete description…. The incomplete description is the design artefact, not the instantiation of the design.... The value of an explanatory design theory lies in its ability to explain a range of phenomena rather than a specific instance of a problem.		Does not enforce hypothetico-deductive model of the natural sciences. From the perspective of explanatory design theory, such demonstrations add unnecessary complex requirements for completeness.
(Carlsson et al., 2011)	(Adapted from Gregor and Jones 2007) What the system is for, the set of meta-requirements or goals that specifies the type of artefact to which the theory applies and also defines the scope or boundaries, of the theory	Justificatory knowledge. The underlying knowledge or theory from the natural or social or design sciences that gives a basis and explanation for the design (extant theories)	Constructs, representations of the entities of interest in the theory	Principles of form and Function. The abstract "blueprint" or architecture that describes an IS artefact, either product or method/intervention…. Principles of implementation. A description of processes for implementing the theory (either product or method) in specific contexts.	Expository instantiation. A physical implementation of the artefact that can assist in representing the theory both as an expository device and for purposes of testing	Testable propositions, truth statements about the design theory.

Appendix 4: Practical Examples for Information Processing Tasks

Example for each construct:

Construct	Definition	Practical Example
Interpreting	**Analyse data to come to an understanding of symptoms. Compare normal to abnormal**	*His BP is low, especially for a person who is normally hypertensive.*
Discriminate	**Distinguish relevant from irrelevant information; recognise inconsistencies, narrow down the information to what is most important and recognise gaps in cues collected**	*His temp is up a bit, but I'm not too worried about it – I'm more worried about his BP and Pulse*
Relationships	**Discover new relationships or patterns; cluster cues together to identify relationships between them**	*His BP went up after his pain score become high*
Match	**Current situation to past situation or current patient to past patient**	*His BP is low, but that is normal for this patient in the morning*
Predict	**Predict an outcome**	*Based on his pattern of deterioration, I predict this patient might go into shock.*

Appendix 5: Phase 1 Data Collection Interview Guide

Decision				
NEWS Score: Protocol				
Patient Context	**HCP Context**		**Ward Context**	
	Speciality		# Beds	
	Nurse knows patient medical history? (Relationship with Patient)		Avg. daily throughput	
	Experience in ward		Dominant patient type	
	Overall Experience		Time pressure on nursing staff	
	Staff Position			
Did the NEWS chart help you in <u>interpreting</u> the data for this patient in this case? How? / Why Not?				
Did legacy charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes			
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes			
Did the design of the chart help you to <u>discriminate</u> between irrelevant and relevant information for this patient in this case? How? / Why Not?				
Did legacy charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes			
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes			

Did the design of the chart help to find relationships or patterns for this patient in this case?? How? / Why Not?	
Did legacy charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you match this situation to past situations? How? / Why Not?	
Did legacy charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you to predict outcomes for this patient? How? / Why Not?	
Did legacy charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Other Comments In what other ways do you look at the chart to identify the health of a patient?	

Appendix 6: Phase 2 Data Collection Interview Guide

Decision				
NEWS Score: Protocol				
Patient Context	**HCP Context**		**Ward Context**	
	Speciality		# Beds	
	Nurse knows patient medical history? (Relationship with Patient)		Avg. daily throughput	
	Experience in ward		Dominant patient type	
	Overall Experience		Time pressure on nursing staff	
	Staff Position			
Did the NEWS chart help you in <u>interpreting</u> the data for this patient in this case? How? / Why Not?				
Did eNEWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did EWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did the design of the chart help you to <u>discriminate</u> between irrelevant and relevant information for this patient in this case? How? / Why Not?				
Did eNEWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did EWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		

Did the design of the chart help to find relationships or patterns for this patient in this case?? How? / Why Not?	
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you match this situation to past situations? How? / Why Not?	
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you to predict outcomes for this patient? How? / Why Not?	
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Other Comments In what other ways do you look at the chart to identify the health of a patient?	

Appendix 7: Phase 3 Data Collection Interview Guide

Decision				
NEWS Score: Protocol				
Patient Context	**HCP Context**		**Ward Context**	
	Speciality		# Beds	
	Nurse knows patient medical history? (Relationship with Patient)		Avg. daily throughput	
	Experience in ward		Dominant patient type	
	Overall Experience		Time pressure on nursing staff	
	Staff Position			
Did the NEWS chart help you in interpreting the data for this patient in this case? How? / Why Not?				
Did eNEWS V2.0 chart help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did eNEWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did EWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did the design of the chart help you to discriminate between irrelevant and relevant information for this patient in this case? How? / Why Not?				
Did eNEWS V2.0 chart help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did eNEWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		
Did EWS charts help you to perform this function?		No 1 – 2 – 3 – 4 – 5 Yes		

Did the design of the chart help to find relationships or patterns for this patient in this case?? How? / Why Not?	
Did eNEWS V2.0 chart help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you match this situation to past situations? How? / Why Not?	
Did eNEWS V2.0 chart help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did the design of the chart help you to predict outcomes for this patient? How? / Why Not?	
Did eNEWS V2.0 chart help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did eNEWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Did EWS charts help you to perform this function?	No 1 – 2 – 3 – 4 – 5 Yes
Other Comments In what other ways do you look at the chart to identify the health of a patient?	

Appendix 8: The Framework for REVIEWS V1.0

The Framework for REVIEWS (V1.0)	
Support for the Four Basic Visual Perceptual Approaches	
	Association and Differentiation
1a	In order to facilitate initial interpretation of vital sign data, each vital sign should be assigned a proprietary plotting area.
	Ordered Perception
2a	In order to facilitate the user in perceiving the ordered value of data, the date and time of vital sign recordings should be incorporated in the visual representation.
2b	In order to facilitate the user in perceiving the ordinal value of vital sign data, colour coding should be applied to the vital sign ranges in which scores are associated with the vital sign recorded.
2c	In order to facilitate the user in perceiving the ordinal value of vital sign data, instructions for understanding the colour coding system should be presented.
2d	In order to facilitate the user in perceiving the ordinal value of vital sign data, preferential placement should be given to vital signs perceived by HCPs as being most important.
2e	In order to facilitate the user in perceiving the ordinal value of vital sign data, a label should be written above the data point recorded.
	Quantitative Perception
3a	In order to facilitate the user in perceiving the ordinal value of vital sign data, vital sign values should be incorporated in the visual representation.
3b	In order to facilitate the user in perceiving the quantitative value of data, vital sign unit markers should be displayed on both edges of the relevant axis.
3c	In order to facilitate the user in perceiving the quantitative value of data, a standardised approach to chart design should be employed.
Support for Gestalt Grouping Qualities	
4a	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of proximity, should be supported.
4b	In order to facilitate the user in detecting objects and identifying patterns

	among the objects, the Gestalt grouping quality of similarity, should be supported.
4c	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of symmetry, should be supported.
4d	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of good continuity, should be supported.
4e	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of closure, should be supported.
4f	In order to facilitate the user in detecting objects and identifying patterns among the objects, the Gestalt grouping quality of inference of common fate, should be supported.
Consistency with User's Stored Knowledge	
	The invariant and the components
5a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate appropriate labels for each variant in the chart.
	The number of components
6a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate the same number of variants.
	The length of the components
7a	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate two planar dimensions in homogenous, rectilinear and orthogonal manner.
7b	In order to maintain consistency with a user's stored knowledge, the design of the chart should be similarly sized to charts users are already familiar with.
7c	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate colour coding that is consistent with the user's stored knowledge.
7d	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate lines to connect ordered data points.

7e	In order to maintain consistency with a user's stored knowledge, the design of the chart should incorporate shapes that are consistent with the user's stored knowledge.
	Support for Analogical Reasoning
8a	In order to support analogical reasoning, the individual needs to be able to physically compare an individual patient's chart to previous charts for said patient.
	Support for Novel Design Features
9a	In order to support the integration of novel design features on observation charts, instructions for using the novel feature should be incorporated into the chart design.

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