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EFFECTS OF INFORMATION DISPLAY ON THE CONSTRUCTION OF CLINICIAN MENTAL MODELS

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EFFECTS OF INFORMATION DISPLAY ON THE CONSTRUCTION OF
CLINICIAN MENTAL MODELS

A

DISSERTATION

Presented to the Faculty of
The University of Texas
Health Science Center at Houston
School of Health Information Sciences
in Partial Fulfillment

of the Requirements

for the Degree of

Doctor of Philosophy

by

Constance M. Johnson, M.S., R.N.
Houston, Texas

Date of Graduation (October 13, 2003)

Dedication

for Laura E. Johnson

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Abstract

Objective: To determine how a clinician's background knowledge, their tasks, and displays of information interact to affect the clinician's mental model.

Design: Repeated Measure Nested Experimental Design

Population, Sample, Setting: Populations were gastrointestinal/internal medicine physicians and nurses within the greater Houston area. A purposeful sample of 24 physicians and 24 nurses were studied in 2003.

Methods: Subjects were randomized to two different displays of two different mock medical records; one that contained highlighted patient information and one that contained non-highlighted patient information. They were asked to read and summarize their understanding of the patients aloud. Propositional analysis was used to understand their comprehension of the patients.

Findings: Different mental models were found between physicians and nurses given the same display of information. The information they shared was very minor compared to the variance in their mental models. There was additionally more variance within the nursing mental models than the physician mental models given different displays of the same information. Statistically, there was no interaction effect between the display of information and clinician type. Only clinician type could account for the differences in the clinician comprehension and thus their mental models of the cases.

Conclusion: The factors that may explain the variance within and between the clinician models are clinician type, and only in the nursing group, the use of highlighting.

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INTRODUCTION

Safe patient care is delivered by a collaborative effort of a team of clinicians with different, yet complementary skills, training, goals, responsibilities, and knowledge. While nursing focuses on diagnosing functional problems, and observing and reporting changes in physiological status (Simpson, 1998b), the physicians center on diagnosing, treating, and managing medical problems. In such a setting, one critical component affecting the quality of patient care is each clinician's understanding of a patient's situation, including the patient's present state, possible future state, and the course of testing and treatment. A clinician's understanding of a patient affects how the clinician interprets new information and makes decisions regarding the patient's management. Schoop and Wastel (1999) provide an example of how a physician and nurse differently interpret the urine incontinence of a patient. The physician immediately diagnoses the patient as incontinent, whereas, the nurse defines it as a functional problem since the patient is aware of when to go to the toilet, but can't hold the urine for a long time. These differences are related to different professional perceptions of the situation and can lead to different treatment approaches.

The different role and background of physicians and nurses may result in different views of the patient. If these views of the patient are too divergent, communication and coordination of care will suffer. A landmark study of 13 intensive care units revealed that poor coordination of care between physicians and nurses resulted in higher than expected mortality rates (Knaus, Draper, Wagner, & Zimmerman, 1986). A retrospective Australian survey of hospital admissions found that communication problems were the most common cause of morbidity and mortality (Zinn, 1995).

Although decisions made in healthcare may be individual decisions, the information needed to make these decisions come from a team of interacting clinicians. This interactive nature of information was exemplified in a study which examined the discussion of patient information among a mixed-status clinical team that showed that groups only discuss 44% of shared information and only 24% of unshared information (Christensen et al., 2000). Thus, a clinician's understanding of a patient must play two, somewhat competing, roles—it must encompass a view that is unique to the clinician's tasks, which necessarily differ from those of others in the team, but it must also be communicable with the views of other team members, so as to support effective collaborative care.

While there is an understanding about the differences in roles of physicians and nurses, no empirical studies document differences between physicians and nurses in their understanding of patients and how these differences affect patient care. A review of the literature showed that the majority of work in roles of physicians and nurses are in the area of their divergent professional roles as exemplified in the cure vs. care paradigm (Baumann, Deber, Silverman, & Mallette, 1998; McMahan, Hoffman, & McGee, 1994). A search of Medline using various mesh terms such as doctor and nurse, interprofessional collaboration, and nursing versus medical models produced well over 1,000 citations, the majority of these focused on problems with collaboration, communication, and conflict between the professions. Within this search as well, there appeared to be very few empirical studies, with the majority of the literature being rhetorical or editorial. Examining the similarities and differences between how physicians and nurses conceptualize patient problems has implications for improving doctor-nurse

collaboration, communication, and may contribute to the understanding of the cognitive needs of these potential users of the electronic medical record.

This dissertation examines the similarities and differences within and between clinicians (physicians and nurses) comprehension and the resulting mental model of a patient derived from a mock patient record. Mental models are dynamic representations the mind constructs from a collection of knowledge to use for problem solving and decision-making (Greeno, 1983; Schumacher & Czerwinski, 1992). A clinician's mental model of a patient represents his or her understanding of that patient, thus allowing the clinician to reason about the patient's problem.

Mental models affect a person's problem solving and decision-making in several ways. Gentner and Gentner (1983) describe how mental models can be used as a means to make inferences about the state of a situation or problem. For example, a physician may infer a disease from a cluster of findings. Second, mental models can be used to create reasons about a particular situation or to validate a particular decision. As in the previous example, the physician may use his/her mental model of a disease to validate their reasons for ordering particular tests. Third, they can serve as way to assist memory (Gentner & Gentner, 1983). Fourth, a person's mental model may also affect how they interpret new information, meaning that two clinicians with different mental models may interpret the same information in different ways (V.L. Patel, Groen, & Frederiksen, 1986). Essentially, they help people to explain, clarify, and foresee events in their particular domain (Mathieu, Goodwin, Heffner, Salas, & Cannon-Bowers, 2000).

A clinician's comprehension and thus, mental model, depends on the interaction of the person's background knowledge and training, the task or the task they must do, and

how the information they use to build a mental model is displayed or represented in the external environment (Endsley, 2000; V.L. Patel, Arocha, Diermeier, Greenes, & Shortliffe, 2001). The background knowledge of a clinician can affect collaborative care. Although it is assumed that different types of clinicians such as physicians and nurses build dissimilar mental models due to their divergent professional goals and training, it is also believed they have shared mental models. On one hand, the dissimilarity in their mental models is directly reflective of their practice models and in a collaborative setting such as healthcare; dissimilar mental models can have positive and negative effects. The positive aspect is that each clinician has a specific role in patient care and these are different for individual clinicians and thus necessarily require different mental models of the patient. The negative aspect is that different mental models can lead clinicians to interpret new information differently, resulting in possible decision-making errors, as well as miscommunication within teams of interacting clinicians. On the other hand, certain aspects of their shared mental models are related to their task demands (Stout, Cannon-Bowers, & Salas, 1996). These shared mental models which are critical to team functioning as in the healthcare environment allow members of the team to foresee the information and resource needs of their co-workers (Stout et al., 1996). The extent and nature of these differences and similarities within and between clinician types such as physicians and nurses has not been studied.

The display of information also affects the development of the mental model. Research has shown that the way information is represented influences how a problem is comprehended and solved (Kleinmuntz & Schkade, 1993; Simon & Hayes, 1976). In information integration, making salient cues such as by highlighting can influence what

information is attended to and considered useful in decision-making (Payne, 1980) with either positive or negative results depending on whether the display salience matches the user's needs. It is well documented that poor information displays can lead to inefficient care which may include redundant ordering of tests or missing information important to the diagnosis of the patient (Tang & Patel, 1994; Bates et al., 1999; Tierney, McDonald, Martin, & Rogers, 1987). There is an understanding that too much information can overwhelm a user and not enough can lead to medical errors. Patel et al. (2001, p. 53) aptly state that "the way that individuals perceive the external world, based on their internal representation of the relevant reality, determines their performance". In essence, if external information presented to the clinician doesn't enhance their internal representation, then errors can be made or inefficiencies can occur. The key is having the right information in the right place for the right clinician. Clinicians need a concise conceptualization and representation of complex clinical data for accurate problem solving and decision-making. Thus it is important to additionally study how the same and different displays of identical information affect mental model construction.

Given the effect of mental models on clinical reasoning and decision-making, the study presented here evaluates how the different backgrounds and tasks of physicians and nurses interact with information displays to affect mental models. Specifically, this study examines the effects of clinician background and display formats on the clinician's understanding of the patient. The results of this research will provide insight into the mental models constructed by clinicians and will assist in contributing to the theoretical foundation of interface display in the medical domain.

Two hypotheses are evaluated:

1. The same information display will lead to different mental models among different types of clinicians.
2. Different displays of the same information will lead to different mental models within the same clinician type.

The study tests these hypotheses by using propositional analysis to analyze verbal protocols of clinicians in a controlled laboratory setting. Propositional analysis was used to construct a text-based model of the patient summaries generated by the clinicians, which in turn reflect the mental models of the clinician. Idea units were identified and inter-relationships compared. Propositional analysis is a formal method for representing natural language to determine how information is represented internally from different external sources and how these representations are changed and integrated. Thus, it is a technique that focuses on the organization of knowledge structures and the processes that operate on them (V.L. Patel & Arocha, 1995). Pilot work in this area has shown it to be a feasible way to assess mental models constructed by physicians and nurses.

The proposed research is significant because it will empirically determine how a clinician's task and background knowledge interact with healthcare display formats to affect a clinician's mental model. This information will contribute to the theoretical framework on how clinicians potentially process information differently and thus will have implications for the display of clinical information for the electronic medical record that directly supports the work of the clinicians.

The hypothesis that the same display of information could lead to different mental models among different clinicians is significant because these differences could be a source of medical errors. This conclusion can also be applied to the second

hypothesis that different displays of information will lead to different mental models for the same clinicians. Bogner (1994) states that errors occur due to insufficient information processing in cognitive tasks. Several investigators have argued that medical errors result from systems that encourage errors (Bogner, 1994; Kohn, Corrigan, & Donaldson, 1999; Shalala, Herman, & Eisenberg, 2000). Therefore, it is important to understand the fundamental cognitive mechanisms that affect medical errors, and how an interface can contribute to the source of these errors. In knowledge-based systems that clinicians will rely upon to formulate specific patient management strategies, it becomes crucial that these tools do not lead to unintentional harm. The current state of informatics technological growth offers the potential for the creation of tools to assist in the reduction of medical errors. According to Kohn et al. (1999), technology can be advantageous, since it can assist in removing options for people to make errors. Specifically, expertly designed information systems need to directly support the tasks of the providers and need to represent information in a way that supports the cognitive activities of the providers.

It is assumed that different types of clinicians build dissimilar mental models due to their divergent professional goals, yet these differences have not been comprehensively examined within the context of the display of information. Some differences will be implicit due to the different goals of different types of clinicians. The design of the medical interfaces should exemplify the mental models constructed by clinicians according to their respective professional theoretical and practice models. If medical interfaces closely follow the mental models of the clinician, it is hypothesized that there will be greater efficiency in the use and comprehension of the information within these medical interfaces. Furthermore systems that are designed to match the users' model

result in systems that are easily "learnable, usable, and functional" (Norman, 1988).

Healthcare professionals need easy to use tools to assimilate a myriad of information, make a diagnosis, and provide optimal treatment. Understanding how the display of information influences their construction of these mental models should be the first step in designing systems that match the goals of its users. Efficient healthcare information systems should enhance clinician skills in improving patient care and minimize time spent in documenting patient care. It is conjectured that once this process is modeled, this information can then be applied more globally. Quality patient care depends on the quality and presentation of patient data and the cognitive science approach is a valuable framework for determining how this information should be structured.

Summary

The purpose of this study is to evaluate how the different backgrounds and tasks of physicians and nurses interact with information displays to affect their mental models. It is hypothesized that the same and different types of clinicians' understanding of a patient are influenced by their background knowledge and training and the display of information. The mental model that a clinician needs to do his or her tasks directly influences the information that must be displayed in an interface, as well as how it is organized and represented. Likewise, a clinician's professional training and background will influence the process by which he or she interprets information, thereby adding additional constraints on the information presented and how it is best organized and represented to facilitate mental model construction.

Being able to operationalize the mental models of physicians and nurses reliably and validly requires an understanding of their cognitive processes. The established

methodology used in determining how people mentally represent information has involved the analysis of text documents or interviewing experts, and thus encoding knowledge and ideas after they have been orally expressed (V.L. Patel, Arocha, Diermeier et al., 2001). This has been accomplished through the use of the think-aloud technique (Ericsson & Simon, 1984) using propositional analysis (Frederiksen, 1975), a formal methodology in cognitive science for representing textual information. Additionally, this research has been guided by studies in the area of memory, comprehension, and understanding (V.L. Patel & Arocha, 1995). While much research has been conducted in this area (Kushniruk & Patel, 1998; V.L. Patel & Arocha, 1995; V.L. Patel, Arocha, Diermeier et al., 2001; V. L. Patel, Kaufman, Arocha, & Kushniruk, 1995; Arocha & Patel, 1995), there is a paucity of research specifically in the area of how the different background knowledge, tasks, and displays of information affect the mental models of physicians and nurses.

The quality of patient care is dependent on the collaborative efforts of a team of interacting clinicians and their understanding of the patient's situation, which includes the patient's past, present, and potential future states. Thus a clinician's understanding of a patient affects how the clinician interprets new information and makes decisions regarding the management and care of the patient. Although the different backgrounds and roles of physicians and nurses may result in a different understanding of the patient, if these views are conflicting or too dissimilar, communication and coordination of care may suffer. Thus, examining the differences and similarities between how physicians and nurses conceptualize patient problems has implications for improving physician-nurse collaboration, the delivery of safe patient care, clinical decision-making, clinical

communication, and may contribute to the understanding of the cognitive needs of these potential users of the electronic medical record.

REVIEW OF THE LITERATURE

This section reviews the pertinent literature on mental models, and differences in clinician practice models and problem solving. This section also reviews the literature on how the representation of information can affect problem solving and decision-making, and overviews the operational methods to elicit clinician mental models.

Mental Models

The interaction between a person's background knowledge, their tasks and how information is represented can influence their comprehension of a patient and that patient's problems. Clinician comprehension affects their problem solving and decision-making in a particular task and/or situation. Medicine is an intensely information rich activity, and unless the presentation of patient information enhances the mental models of the practitioners, users can be easily overwhelmed by the volume of information and will have difficulty interpreting and assimilating the information. An understanding of the mental models constructed by clinicians and how their background knowledge, their tasks and information display affects their mental models is thus studied to add to our scientific body of knowledge. This section provides an overview of mental models, the development of mental models in text comprehension, the effect of mental models on decision-making, and the significance of shared mental models. Additionally this section reviews methods such as propositional and semantic representation of information that have been successfully used to study physician reasoning and decision making.

What is a Mental Model?

There is no agreement on what a mental model is or how to measure the mental model of a person. First, there is a theoretical problem where there is conflict and

confusion regarding the definition of mental models. This problem has been discussed over the years with no real solution (Rouse & Morris, 1986). Second, there is a methodological problem related to the definitional problem. How can we accurately measure a concept that has a confusing definition? There are several different definitions of mental models that have arisen from research over the last 60 years. This section will provide an overview of these definitions.

The concept of mental models was first proposed by Kenneth Craik in 1943 who put forward that mental models are mental representations that are created from genuine, theoretical, or invented situations (Craik, 1943). He suggested that the mind creates “small-scale models” to foresee events, and to provoke thoughts and inferences. Craik’s theory emphasizes three aspects of mental models. First, mental models are internal belief structures that symbolize an external situation. Second, they are created and influenced by thought processes in order to accomplish cognitive tasks. Third, mental models are adapted to the circumstance of the situation or environment (Craik, 1943).

Johnson-Laird’s theory of mental models was the most influential of all of the theories. The theory provides a broad description of thought, reasoning, and language comprehension (Johnson-Laird, 1983). The theory seeks to explain reasoning and emphasizes that people not only consider the syntactic structure of a problem, but also the semantic content. Thus, when reasoning about a problem, people make inferences about the meaning of the problem and build a mental model from the important information of the problem. The mental model is thus constructed by correlating an individual’s

collection of knowledge with external information (Johnson-Laird, Byrne, & Schaeken, 1992).

Holland, Holyoak, Nisbett, and Thagard (1986) hypothesize that mental models are the basis for all reasoning processes. Schumacher and Czerwinski (1992) characterize mental models as:

- Continually evolving and incomplete
- Typically containing errors and contradictions
- Simplified explanations of complex phenomena
- Contain measures of uncertainty about their validity that allow them to be used even if they are incorrect
- Represented by sets of condition-action rules

Essentially mental models suggest how individuals infer the probability of an event from their knowledge of ways an event might occur (Boltzmann, 1899), and they provide an explanation of deductive and probabilistic reasoning. Since they are dynamic constructions of what an individual knows, they are considered multidimensional and continuously changing. For the purposes of this study, I define mental models as collections of knowledge that allow individuals to explain and predict events through their perceptions of the event, their comprehension of the event and their reasoning about the event.

The Development of Mental Models

The development of mental models occurs through three processes. These are perception, comprehension, and reasoning (Johnson-Laird, 1989). Perception is considered the initial source of mental representations. It is through our perception of the

world that information is conveyed to us through our senses. Johnson-Laird (1989) proposed that what is perceived is dependent upon our internal representation and on the external representation or essentially what is in the world. So perception is how information is integrated into conscious processes, and how we formulate this information into thoughts and ideas, which are dependent upon our collection of knowledge. Thus begins the process of comprehension.

Mental representations begin to form from our understanding of what is carried in memory and what is perceived from the outside world. They are dependent upon our collection of knowledge (Bransford & Johnson, 1971). Comprehension is defined as “the act of understanding and inferring possibilities based on past experiences” (Angeles, 1992, p. 49). Thus comprehension needs the collection of knowledge and beliefs that a person carries in order for the new information to be contextualized and comprehended (Clark, 1977). Research in the area of mental models has also focused on how people construct mental models from narrative comprehension. Bower and Morrow (1990) proposed that an understanding of text passages begins with a translation of the text into conceptual propositions. These conceptual propositions are then linked to a reader’s background knowledge to enable the drawing of inferences and causal relations and thus the building of mental representations or mental models (Bower & Morrow, 1990). Comprehension is a significant facet that can affect performance in a situation and is a prerequisite for reasoning, problem solving and decision-making. It is dependent on where attention is focused, background knowledge and the ability to use underlying knowledge in certain situations (V.L. Patel, Arocha, & Kaufman, 2001).

Deductive reasoning is a process that involves transforming mental representations that result from the comprehension process (Rips, 1983). Reasoning about a situation and making inferences about this situation thus does not extend beyond the scope of the comprehension process (Johnson-Laird & Byrne, 1991). Reasoning refers to the ability of abstracting and inferring from an understanding of the world. Kant views reasoning and comprehension as two intellectual capacities (Angeles, 1992). Comprehension, on one hand contains a priori ideas by which it configures experience. Reasoning, on the other hand, is the ability to infer. As Kant states it is the “overseer of what is possible and impossible” (Angeles, 1992, p. 255). Thus it is through the process of perception, comprehension, and reasoning that internal representations are formed.

Although there has been some work done in clinical case comprehension and reasoning (Coughlin & Patel, 1987; V.L. Patel & Groen, 1986), these results show some differences from earlier work done on the theory of text comprehension (Kintsch, 1988). The theory of text comprehension involves the integration of bottom-up processes and top-down processes. The bottom-up process consists of a representation of the text in memory, whereas the top-down process consists of the general actions or events referred to by the text and the comprehension results from the integration of a person’s prior knowledge with the text (Kintsch, 1988). Whereas in medical comprehension Arocha and Patel (1995) suggest a two stage process; a rule-based construction process and an integration process. In this comprehension-based approach, the rules are triggered by the problem shown in a clinical case and merged into an understandable representation in the integration process (Arocha & Patel, 1995). Therefore, comprehension is built upon prior knowledge and integration of the clinical case. Once comprehension has occurred,

inferences and reasoning about what is understood can occur. Although reasoning is an extension of comprehension, it is our basic understanding that allows reasoning to occur.

Shared Mental Models

Other work in the area of mental models concerns individual versus shared mental models. The basis for shared mental models is that people have some common knowledge in long-term memory which Clark (1996) refers to as “common ground”. The idea is that one part of everyone’s mental model in a group situation is alike for all of them together (Van der Veer & del Carmen Puerta Melguizo, 2003). Although people can have shared group knowledge, which is different than mental models, the mental models that they construct may not be instantiated in the same way. For example, clinicians have the same anatomy and physiology knowledge, but how they reason and infer in new situations may differ per individual depending upon the situation. There may be some homogeneity within each individual’s mental model within the group, but it may not be exactly the same for everyone within the group. Thus, an individual’s mental model does not exactly equal the group’s model since models tend to be unstable, incomplete, and are continuously evolving. An important finding of the work presented in this document, will be a measure of how each clinician’s model is shared.

Comment on Mental Models

There are several critiques regarding mental models. The major problem with the theories regarding mental models is the nature of their incompleteness. The problem is due to human variability and the difficulty, if not impossibility, to render all alternatives explicitly (Dreyfus, 1972). Yet, Hayes (1985) has argued that defining intuitive knowledge is not impossible, but may be extremely time consuming.

Patel, Arocha, and Kaufman (2001) propose the same argument that internal representations change from individual to individual, regardless of the same basic collections of knowledge. Although the basic collections of internal knowledge may be the same for many individuals, individual experience, and how individuals comprehend new information and reason with it may vary between individuals. This problem stresses the importance of careful measurement of clinician mental models.

The overall problem with explicitly modeling mental models is the absence of theoretical constructs in many related areas of cognitive science such as theories relating to human perception, reasoning, and discourse. Johnson-Laird (1989) proposes that the reason for the deficiencies is the absolute difficulty of formulating a general theory on mental models.

One other limitation of studies on mental models as discussed by Rouse and Morris (1986) revealed that the scientist's mental models steer their conceptualizations of mental models which in turn dictate how they are measured and analyzed. They propose that this interjects too much subjectivity and arbitrariness into the scientific process of the study of mental models and is akin to the development of models of other people's models. Although they state that this can't be avoided, they argue that in the study of mental models, these biases must be carefully considered (Rouse & Morris, 1986).

The limitations in studying mental models cannot be overlooked. Internal representations are difficult to measure. Yet it is proposed that with the use of verbal protocols such as the talk-aloud technique and the use of propositional analysis as a means for analyzing the summations made by the clinicians, the differences between the mental models developed by different clinician types can be adequately measured.

Differences in Clinician Practice Models and Problem-Solving

To understand how background knowledge affects the comprehension differences between physicians and nurses, the unique perspective of their discipline must be reviewed. The manner in which physicians and nurses gather, interpret, and use patient data differs due to the differences in their approaches to patient care. The physician's approach centers on diagnosing, treating, and managing medical problems. On the other hand, the nursing approach focuses on identifying high risk individuals, diagnosing functional problems, and observing and reporting changes in physiological status (May, 1992; Simpson, 1998b). This has sometimes been referred to as the "care vs. cure" paradigm and may cause physicians and nurses to communicate different aspects of the patient's clinical picture.

Differences in different types of clinician problem-solving skills within the area of medicine have not been well defined. Although many studies have focused on the mental process of physician problem-solving (Arocha & Patel, 1995; Coughlin & Patel, 1987; V.L. Patel, Arocha, & Kaufman, 1994; V.L. Patel & Groen, 1986; Schmidt, Norman, & Boshuizen, 1990), few studies have focused on the mental process of nurse problem-solving. Many of these studies have been based upon differences between experts and novices within specific domains.

Domain specific problem solving is the manner through which an individual makes decisions based on previous knowledge and experience in a specific area. During the process of problem solving, an individual develops an internal representation that consists of the elements of the problem and the links between the elements. Inferences are then drawn from the knowledge base of the individual solving the problem

(Hassebrock, Johnson, Bullemer, Fox, & Moller, 1993). The ease with which an individual can solve the problem lies in her/his ability to establish an association between the external information and internal models through inferred relations and pattern recognition (Chi, Feltovich, & Glaser, 1981).

One model proposes that physician thinking is based on the hypothetico-deductive model that focuses on data driven hypotheses and leads to hypothesis driven data selection. The process is an iterative process and continues until one or more diagnoses are made from the data and/or observations (Hersh, 1999).

Another model proposed by Schmidt, Norman, & Boshuizen (1990) is that physicians gather small amounts of data and diagnosis the problem(s) with a smaller number of hypotheses. These authors propose that physicians use “illness scripts” (Schmidt et al., 1990, p.66) to arrive at the correct diagnosis. They define “illness scripts” as knowledge based upon learned knowledge and experience that are centered in causal networks. Medical education is structured to teach scripts of patient signs and symptoms under diagnostic labels (Hersh, 1999).

There have been many studies concerning the mental processes of physicians in their task of diagnosis. Elstein and Shulman (1978) found a lot of variance in physician performance on different problems by the same physician. Patel et al. (1989) found that physicians use very little basic science in their efforts to make a diagnosis, but rather linked patient problems directly to various diseases as found in building scripts.

Studies in the domain of nursing on critical thinking skills and problem solving are very limited. These studies have mainly focused on the differences between expert and novice nurses (Benner, 1984; Benner, Tanner, & Chesla, 1992; MacLeod, 1994).

Benner's work in skill acquisition in nursing parallels other findings in the general area of problem-solving such as the expert's ability to recognize patterns (Benner, 1984). In a study of third-space fluid shift problems, expert nurses selectively gathered more cues and made more inferences than novice nurses (Redden & Wotton, 2001). A study by Lauri and Salanterä (1995) found that abstraction of nursing knowledge was associated with innovative decision-making.

There has been a significant amount of work done on how clinical experts and novices differ in their comprehension of the patient and their approach to patient care, but there is no specific literature that shows how the background knowledge, the tasks and the information display affects the mental models of physicians and nurses.

Representation of Information

Research in the area of decision-making processes demonstrates how the display of information affects these processes. Features in information displays that should be considered when evaluating the effects of the display on decision processes are the overall structure of the display, the form of the display, and the sequence of information within the display (Kleinmuntz & Schkade, 1993; Schkade & Kleinmuntz 1994). In a study that examined the effect of information display on decision-making, researchers found that while organization influenced information acquisition and form influenced information combination and evaluation, sequence did not affect information acquisition (Schkade & Kleinmuntz 1994). However, in other studies regarding sequence of information, it was found that the order of the presented information was significant to the outcome of the decision (Hogarth & Einhorn, 1992; Perrin, Barnett, & Walrath, 2001). Decision-making involves both internal representations and external

representations. Internal representations are arrangements of knowledge that reside in memory, such as propositions, schemas, mental models, etc. and require the retrieval of information from long-term and working memory through methods of cognition (Zhang, 1997). External representations are arrangements of knowledge in the environment such as objects, symbols or dimensions (Zhang, 1997). Studies on external and internal representations have traditionally acknowledged a difference between the two and have had dissimilar views on their interactions. Some view external representations as information used by the mind for computational processes, meaning that the information forms internal models within the mind, computations are performed on it, and this information is then deciphered and then externalized (Newell, 1990). However, the distributed cognition approach shows that when cognitive tasks involve both internal and external representations, the information is neither exclusively external nor exclusively internal, but both (Zhang, 1997). Zhang proposes that external representations are not simply memory aids or tangential to internal representations, but are fundamental to the tasks they direct and can establish the direction the mind functions around the task (Zhang, 1997). Determining how the interaction between the background of the clinician, the type of clinician and the display of information affects mental models of the clinicians will help in deciding the best ways to represent this information in healthcare applications to support appropriate mental models.

Johnson-Laird (1983) suggests that reasoning about a problem is facilitated if a person makes use of a mental model that characterizes the significant information in a suitable fashion for the problem to be solved. A series of investigations showed that when individuals are presented with a problem in the abstract form, only 12% are able to

solve it. However, when an equivalent problem is presented using objects and familiar context, 60% are able to solve the problem (Wason & Johnson-Laird, 1972). This study demonstrated that people are able to solve problems more easily when they can relate their existing knowledge to a problem because the structure of the information presented matches the structure of the existing knowledge. Designing an effective interface for the medical record requires the designer to identify the appropriate user-knowledge to be cued, and then present relevant information to the user in a context that helps the user construct the most suitable mental model. Efficient and intuitive user interfaces will require designers to consider the mental models constructed by clinicians as they accomplish professional tasks. Different representations of the same abstract task may cause different problem solving behaviors and possibly solutions even if the representation is the same but an abstract level (Zhang, 1997).

The form of a representation determines what can be easily inferred from it. It is well known that people are much better at recognizing than recalling information. If the visual representation of information provides a good conceptual model and good mapping, its use can facilitate recognition of information and enable the use of what Norman (1988) terms “knowledge in the world” rather than “knowledge in the head”. Although there are advantages to both, a good external representation of information may enhance problem solving by decreasing the demands on human cognition. The availability of data alone without a graphic display of information forces the collection, maintenance, and integration of these data mentally which increases the probability of error (Woods, 1991). It has been well-documented that performance is improved when information is displayed extrinsically through pattern recognition rather than intrinsically

through straight text which requires intense cognitive activities such as memory and deduction (Rasmussen & Vincente, 1989; Wickens & Andre, 1990; Woods, 1991). It essentially modifies the weight of the task from cognitive processes that are restricted, such as working memory, to cognitive processes that are more indefinite such as pattern recognition and object perception (Bennett & Flach, 1992).

Salient cues

Certain display factors can distract or guide visual attention. Attention permits a filtering out of needless information, thus allowing a directed focus on information that is important to fulfill a goal (Proctor & Vu, 2003). Attention can be directed in displays of information by highlighting some of the items. The highlighting tells the users that this information should be paid attention to (Hammer, 1999). Although salient items such as highlighting can be used to attract visual attention, they also have the potential to bias decision-making (Wickens & Hollands, 2000). The problem is that people may attend to and believe salient cues arbitrarily and consider background items irrelevant. Relevancy is the critical element when using such cues. This relevancy is known as highlighting validity (Fisher & Tan, 1989). The degree that an individual uses highlighting to assist a search, for example, is based on the individual's belief that the highlighting is valid. In addition, the attention attracting properties of a cue can influence the extent that it will be weighted in information processing (Payne, 1980). Studies that used color in laboratory results to indicate possible clinical significance, showed that subjects identified color coded abnormalities in less time than without the color coding and made fewer errors (Verheij, Hoeke, Bonke, Van Strik, & Gelsema, 1997a, 1997b).

Order of information has been also shown to affect mental models that are constructed from text (Denis & Cocude, 1992; Taylor & Tversky, 1992). These studies showed that information presented at the beginning of text may influence the construction of the mental model. In a decision-making study under time pressure, Wallsten and Barton (1982) found that subjects processed the cues presented at top more than at the bottom of information displays. They postulated that information at the top of the page was more salient to subjects since we tend to read from top to bottom even though the information at the top was not any more important than at the bottom of the page.

In the area of medicine where the correct decision is crucial to the outcome of the patient, it is important that the display salience are compatible with those of the tasks of the user and do not impose unnecessary noise potentially resulting in cognitive overload for the clinicians.

Operational Methods to Elicit Clinician Mental Models

Measurements of cognitive processes have involved various methodologies. Historically, experiments in cognition have focused on the behavior of an individual as they perform a task. Thus, it is believed that by observing a subject's performance, properties of human cognition should be revealed (Bower & Clapper, 1989). The methodologies presented below, which have been extensively used in studies of cognition, are representative of the methods that will be utilized to uncover the cognitive processes of clinicians.

Verbal Protocols

Verbal protocols such as the think-aloud technique are verbalizations made by a subject while performing a task (Kirwan & Ainsworth, 1993). The aim of this technique

is to allow collection of procedural information about mental processing, wherein the investigator can make deductions about the principal cognitive processes of the subject. The theory behind the think-aloud technique assumes that the processes that generate verbal reports are subsets of the processes that generate behavior thus are amenable to an information-processing analysis (Ericsson & Simon, 1984; Simon & Kaplan, 1989). This methodology can also include eye tracking, gestures, and other non-verbal behaviors. Often videotaping is used to record the procedure to allow an in-depth analysis later on. Verbal reports produce massive amounts of data. The key to making this information useful is in how these data are transcribed, segmented, coded, and summarized (Cooke, 1999). The goal is to summarize these data in such a way that the results can be graphically visualized.

Analysis of Mental Models

Propositional Analysis

Patel, Arocha, and Kaufman (1999) describe propositional analysis as a means for analyzing comprehension and problem solving and for representing linguistic information ((V.L. Patel, Arocha, & Kaufman, 1999; V.L. Patel, Arocha, Diermeier et al., 2001). Propositional analysis (Frederiksen, 1975) is a formal method of representing text in cognitive science that has been successfully used in the medical domain (Coughlin & Patel, 1987; V.L. Patel et al., 1994; V.L. Patel & Groen, 1986), and has been used for analyzing representation of meaning in memory (V.L. Patel, Arocha, Diermeier et al., 2001). Propositions are considered hypothetical units that represent the semantic content within the principal framework. They usually consist of a relation such as a verb, adjective, and adverb and arguments such as nouns (Newman, 1994). To conduct a

propositional analysis, a propositional representation of the original text is created to use for comparison. The subject's verbal response is then converted into a semantic network. Patel and colleagues (1999) describe the network as consisting of propositions and links. The propositions are the attribute information, whereas the links are the relational components. For example, the sentence, "her oropharynx showed dry mucous membranes" is analyzed as one proposition or one idea unit. The propositions are then categorized as recalls or inferences. Recalls are those that are drawn directly from the clinical text and inferences are those that are unprompted.

Propositional Types

One method of analysis of verbal protocols involves differentiating between two types of responses in recollecting clinical information. These have been described by Patel and colleagues as recalls vs. inferences (V.L. Patel et al., 1986). Recalls are defined as "reconstructions of portions of a clinical case drawn directly from the original text", whereas "inferences consist of transformations performed on original text based on the subject's specific or general world knowledge". Inferences are considered high level processes which are built on prior knowledge and expertise. Inferences can be forward-driven or backward driven. Forward driven inferences are made in the direction of data to hypothesis, whereas backward inferences are made from hypothesis to data. Hunt (1989) describes forward inferences as knowledge-based and backward inferences as goal based. Recall on the other hand is mainly dependent upon memory. Studies have shown that experts make more inferences than novices do, and novices employ more direct recall (V.L. Patel et al., 1986).

Inferences are considered high level processes, which are conclusions based upon previous knowledge (top-down processing) and experience, and recalls are summaries of the facts and are dependent on memory (Lemieux & Bordage, 1992). A study which examined recall of laboratory data showed that experts were better at recall when they were asked to diagnose versus just memorize the presented case (G. R. Norman, Brooks, & Allen, 1989). The importance of these earlier studies showed that in clinical case comprehension, the significance lies not in merely recall of the case, but the importance and level of abstraction of the information recalled (V.L. Patel et al., 1999).

Studies in the area of medical comprehension have also examined how clinical text is translated into a mental representation of the text. Arocha and Patel (1995) argue that there are two stages in the process of understanding clinical text: rule-based process and an integration process. The rule-based process is activated by the patient's problem, which together form the clinical case narrative, whereas, the integration process merges the rules into a logical representation. They describe that the schemas or mental representations form from an individual's knowledge base and an understanding of the presented case (Arocha & Patel, 1995). Yet if clinical cases are not clearly presented to the clinicians in the way they think about them, the clinicians will have difficulty processing the information, thus comprehending the information.

Summary

This review of literature shows that there are no specific studies that clearly delineate how the interaction between a clinician's background knowledge, their tasks and how information is represented can influence the clinicians' comprehension and thus their mental model of a patient. Although there are many studies concerning mental

models, the differences in the tasks of clinicians, differences in clinician experts and novices, and the effects of information displays on information processing, there are not any specific studies that link all of these together comparing the mental models of physicians and nurses.

Physicians and nurses have different background knowledge and tasks that are reflected in the literature as the “cure” vs. “care” paradigm. The cure model is associated with the medical model and the care model is associated with the nursing model (Baumann et al., 1998). It is through these models that the differences and similarities in clinician comprehension, decision-making, and thus mental model of a patient may be further delineated.

Research in the area of decision-making demonstrates the potential influence of how the display of information affects the decision-making processes. Zhang (1997) proposes that different representations of the same abstract task may cause different problem-solving behaviors and possibly different solutions even if the representation is the same. In the area of medicine where the correct decision is crucial to the outcome of the patient, it is important that the representation of the information does not impose cognitive load, thus potentially affecting the decision-making of the clinician.

Over the years, the term mental model has been used in a variety of disciplines and has been defined in several ways. I define mental models for the purposes of this study as collections of knowledge that allow individuals to explain and predict events through their perception of data, their comprehension of data and their reasoning about data. Although mental models are considered difficult to measure, mental models will be measured here through clinician comprehension with the use of verbal protocols and the

use of propositional analysis as a means for analyzing the summations made by the clinicians.

This study takes into account theories on mental models, clinician practice models, clinician problem-solving and decision-making, and the representation of information to help in understanding how the clinician's background, their tasks, and the display of information interact to affect patient comprehension and thus the development of mental models constructed by physicians and nurses. It is important to study how a clinician's comprehension of new information can affect patient management decisions, communication and coordination of care.

DESIGN AND METHODS

This section presents the conceptual framework, design, methods, results, conclusions, and limitations of a pilot study that was conducted to assess the feasibility of using propositional analysis with eye tracking data to understand the development of clinician mental models. The section also presents the design and methods of the current study that were developed as a result of the findings from the pilot study.

The Pilot Study: Combining Eye Tracking with Think Aloud Protocols

The pilot study examines the feasibility of combining the talk-aloud technique with eye tracking as a process for studying the development of mental models constructed by clinicians when reading an electronic medical record using a methodological triangulation approach. A convenience sample of 5 physicians and 5 registered nurses were recruited to participate in this study. Subjects wore a head mounted eye tracker while reviewing medical cases in the electronic medical record format and dictated a summary of the record. The reported results suggest important implications in understanding the mental models of physicians and nurses. Natural language discourse analyses provided the majority of information needed to understand how clinicians acquire, integrate, and process information. The eye tracking data provided very little complementary data and actually was shown to be a detriment, due to extensive technical problems that were very time consuming, rather than a benefit in the pilot study. This pilot study using methodological triangulation did demonstrate proof of concept and gave directions for the refinement of the current study.

Methodological Triangulation

Triangulation

Using multiple methods allows the investigation of a research question with “an arsenal of methods that have non-overlapping weaknesses in addition to their complementary strengths” (Brewer & Hunter, 1989, p. 17). The main purpose of methodological triangulation is to reveal that different approaches engender not the same results, but evaluate the consistency of the results. It is an approach, which provides consistency checks across the data (Patton, 2002). Arguments against using different methodological approaches to address one research question have been based upon violating the methodological purity of the approaches, since they were originally developed as unrelated approaches (Guba & Lincoln, 1988). Arguments for using different methodological approaches include the practicality of gathering the most relevant information possible and address the issue of decreased error when using multiple methods (Patton, 2002).

While the focus of methodological triangulation is the integration and comparison of data collected through both qualitative and quantitative methods, often these data do not fit together to provide one complete assimilated picture. In point of fact, there may be divergence in the findings between the two approaches. In spite of this, it is important to not discredit immediately one approach or data set above another, but to closely examine areas of the data that intersect and diverge as a means to explain the complex nature of the phenomena under study (Patton, 2002).

Methods to Elicit Clinician Mental Models

Verbal Protocols

The talk-aloud technique, one type of verbal protocol, analyzes verbalizations made by a subject while performing a task (Kirwan & Ainsworth, 1993). The aim of this technique is to allow collection of procedural information about mental processing, wherein the investigator can make deductions about the principal cognitive processes of the subject. See the Review of Literature for a complete review of verbal protocols.

Propositional Analysis

Propositional analysis (Frederiksen, 1975) is a formal method of representing text in cognitive science that has been successfully used in the medical domain (Coughlin & Patel, 1987; V.L. Patel et al., 1986; V.L. Patel et al., 1994) and has been used for analyzing representation of meaning in memory (V.L. Patel, Arocha, Diermeier et al., 2001). See the Review of Literature for a complete review of this type of analysis.

Eye Tracking

Literature on eye movement data reveals that the eyes do not move smoothly over a visual field, but makes a series of sudden jumps called saccades (Haber & Hershenson, 1973). Saccades are considered the principal method for moving the eyes to a different part of the visual field. The characteristic properties of saccadic eye movements or saccades reveal that they generally take about 100-300 milliseconds (ms) to begin and another 30-120ms to complete, and can reach a velocity of 700° per second for large movements (Carpenter, 1988). Their high velocity is thought to diminish time in flight, so that the majority of the time can be spent fixating on targets. Although saccades are

initiated voluntary, they are considered ballistic since once they are started, their path and destination can't be changed (Haber & Hershenson, 1973).

Saccades are generally followed by fixations, which are the stops between saccades and last approximately 200-600ms. During fixation, the eyes are not completely stationary, but exhibit small involuntary movements of less than one degree of visual angle called flicks or tremor. It is during these fixations that most visual information is acquired and processed (Carpenter, 1988). So saccades serve the role of moving the eyes to the target of interest or fixations in the visual field.

Eye movement studies suggest that changes in gaze are directed to the demands of whatever task is at hand (Yarbus, 1967). The task use of gaze is easily understood for reading text, where the eyes move along a line of text making a sequence of fixations and saccadic movements (Kowler & Anton, 1987). Short words are often not fixated and long words frequently receive more than one fixation according to Kowler and Anton (1987). Eye-movement information can provide a significant amount of information about an individual reading text. Eye-trackers record a reader's eye movements as they fixate on words or groups of words within text. By superimposing the location of the gaze onto the text, the investigator can determine exactly where the subject is looking and the length of time of the gaze. Fixation time can provide measures on where the subject is focusing his or her attention. Bower and Clapper (1989) report that this type of record provides an abundant collection of information about where the reader is focusing their attention. Furthermore they state that it is a good method to determine the length of time a reader fixates on a word, or goes back to reread a word or collection of words (regress) (Bower & Clapper, 1989).

Numerous studies have shown that eye gaze plays a central role in the demands of a task. These studies furthermore suggest that gaze control and saccadic eye movements perform a significant role in mediating cognition (Just & Carpenter, 1976; Chase & Simon, 1973; Ballard, Hayhoe, & Pelz, 1995). Additionally, duration of eye gaze may provide a rough estimate of duration of cognitive processes, including a person's mental workload. (Just & Carpenter, 1976). Thus, eye gaze data are quantitative data that are considered an objective approach in the study of cognitive behavior.

Eye Tracking Instruments

The goal of eye tracking is to determine where an individual is looking from the appearance of the individual's eyes. In standard eye-trackers an image of the eye is processed in three steps (Scott & Findlay, 1991). First, the reflection of a light source is found in the eye's image. Second, the pupil's center is determined. Third, the relative position of the light's reflection to the pupil's center is calculated. The gaze direction is determined from information about the relative positions of the eye (Scott & Findlay, 1991). There are many potential sources for error in obtaining reliable and accurate eye movement data. Although the degree of reliability and accuracy of these data depends upon the research in question, McConkie (1981) has set guidelines concerning what might be reported in studies involving eye movement data so that uniform comparisons can be made among studies. He suggests that all studies involving eye movement data should report "characteristics of the signal, algorithms used in reducing data, and accuracy of the eye position data" (McConkie, 1981).

Similarities between Natural Language Discourse Analysis and Eye Tracking

Although natural language discourse analysis generates qualitative data and eye tracking generates qualitative and quantitative data, I hypothesized that these methods could be combined for a richer understanding of cognitive behavior. When eye tracking is used with the talk-aloud technique, information acquisition processes can be both observed and measured. It was originally thought that eye tracking data could complement the propositional analysis in understanding the complex phenomena of how the display of information affects clinician mental models.

Methods

A convenience sample of 5 physicians and 5 registered nurses were recruited to participate in this research study. Exclusion criteria included only the wearing of eyeglasses as the reflection from the glass, prohibited tracking of the eye movements. Given that this study sought to determine the feasibility of the methodology, specialty background and expertise were not considered. A convenience sample was chosen to allow ease of access to a study population. The study was conducted in the Cognitive Science Laboratory at the University of Texas Health Science Center at Houston, School of Health Information Sciences. Written informed consent was obtained according to the Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston prior to participation.

Subjects were first given training on the talk-aloud technique using two-digit multiplication and six character anagram problems. Verbal protocols, such as those produced using the talk-aloud technique, are verbalizations made by a subject while performing a task (Ericsson & Simon, 1984).

The subjects were then fitted to an ISCAN eye tracker (ISCAN, Inc., Burlington, MA, U.S.A.), and the system was calibrated according to manufacturer instructions, using 5 fixation points. Eye movement data through eye tracking was collected to determine the information acquisition process. The ISCAN ETL-500 head mounted eye tracker (ISCAN, Inc., Burlington, MA, U.S.A.) was used to monitor the subject's eye movements while reading the text. The ISCAN eye tracker uses a head-mounted camera, infrared light source, and magnetic 3D head positioning system, to track the subject's eye without physical contact to the eye. Eye point-of-regard is determined using the pupil to corneal reflection method. To begin, subjects were provided with a target on the screen, which they had to fixate on until the selection response occurred and the case was presented.

While wearing an eye tracker, subjects were given three contrived medical cases. An emergency room physician created the cases. The cases were presented to the subjects as text based simulations within the format of an electronic medical record in the same order. The diagnoses and order of the three adult cases included one case of upper respiratory tract infection, one case of anxiety, and one case of gastroenteritis. Subjects were instructed that they should read the chart as they would normally, in any order, and that they were free to look at as much or as little information as they deemed necessary. As the subjects were reading the chart, they were instructed to read and state all thoughts out-loud. They were further instructed that after reading each chart, to dictate a summary, during which time they were not allowed to look back at the chart. The computer screen and voice of the subjects were video/audio-taped.

Data Collection and Analysis Process

The study used continuous on-going observation as the subjects reviewed the three cases and summarized each case. Both qualitative (verbal summaries) and quantitative data (eye tracking) were collected through a mixed strategy approach consistent with a triangulation model (Patton, 2002). Although the clinicians' verbalizations were recorded throughout their review of the electronic medical record cases, only the subject's summaries were directly transcribed from the audiotapes into Microsoft Word. To capture the complexity of the summaries that were generated by the physicians and nurses, a propositional analysis (V.L. Patel et al., 1994) was used to create a text-based model of the summaries in which idea units were identified and the inter-relationships compared. A propositional analysis of the original EMR was also done in order to identify which ideas expressed by the subjects constituted either direct recall of the original text, inferences generated from the original text, or un-coded information that was not present in the original text, including erroneous recall of information. Recalls were defined as "reconstructions of portions of a clinical case drawn directly from the original text", whereas "inferences consisted of transformations performed on original text based on the subject's specific or general world knowledge" (V.L. Patel et al., 1986). Since inferences represent an idea that is generated from the information given in the text, inferences are considered to be high-level processes, which, are built on prior knowledge and expertise. For instance, an example of the original text in the study listed the past medical history in one of the cases as "cholecystectomy, 5 years ago and gunshot wound abdomen, treated surgically, 1965." An example of an inference that was made from this original text was "medical history was noncontributory." An example of a

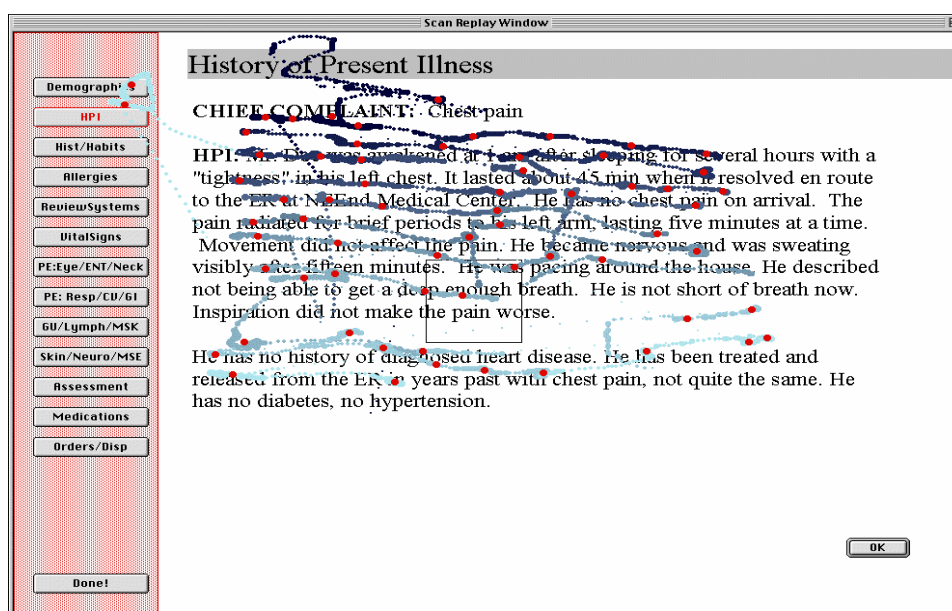
recall that was made was “He has a history of cholecystectomy, 5 years ago.” Finally an example of un-coded text was, gunshot, “5 years ago”. Actually, the cholecystectomy was 5 years ago.

Both analog and digital outputs from the eye-tracking device were recorded. The analog outputs contained the text from the electronic medical record overlaid with continuous eye gaze positions showing the direction of eye movement within the text, as well as fixations. The digital outputs were not analyzed since we only examined fixations, which could be obtained from the analog data. The analog outputs were manually coded for number and location of each fixation within each section of the electronic medical record. Basic demographic data such as occupation and gender and problems with the experimental procedure were additionally collected on all the subjects.

An inductive analysis approach was used to determine themes, patterns and interrelationships among the data. This involved the development of coding and classification schemes to condense the volume of the data, to identify patterns and develop a framework for revealing the meaning of the data (Patton, 2002). This is an iterative process, which first required segmenting the text summaries into propositions. The transcribed text for each case was initially reconstructed into numbered sequential sentences, which were then transformed into numbered propositions. The numbered propositions were then coded as recalls, inferences, un-coded (not present in original text or erroneous data), and categorized by the origin of the EMR section from which they were summarized. The transcribed text was further analyzed to determine order of patient information summarized, which information (chunks) were included/excluded and which information was shared and unshared among the subjects.

Since this was only a feasibility study the analog eye tracking data (see Figure 1.), as shown on the screen displays, were only analyzed on four of the dictated summaries on the anxiety case. For the purposes of analyzing the feasibility of these methodologies, purposeful sampling was used to choose four cases for this analysis. Since qualitative methods permit analysis into selected issues in greater depth and breadth, it was determined that four cases would be enough to determine the feasibility of these methods. The anxiety case from two nurses and two physicians was chosen for the eye tracking analysis. This particular case was chosen since the first case could have been considered the training case and in the third case, there was concern about subject fatigue. The four cases were randomly chosen before the outcomes of these cases were known. It is important to state that the purpose of the study was to determine feasibility of combining these methodologies and that this type of sampling is not representative of the entire sample nor can these results be generalized to the population at large (Patton, 2002). As Patton (2002, p. 241) states “the purpose is credibility, not representativeness”.

Figure 1. Example of analog eye tracking data.



Results

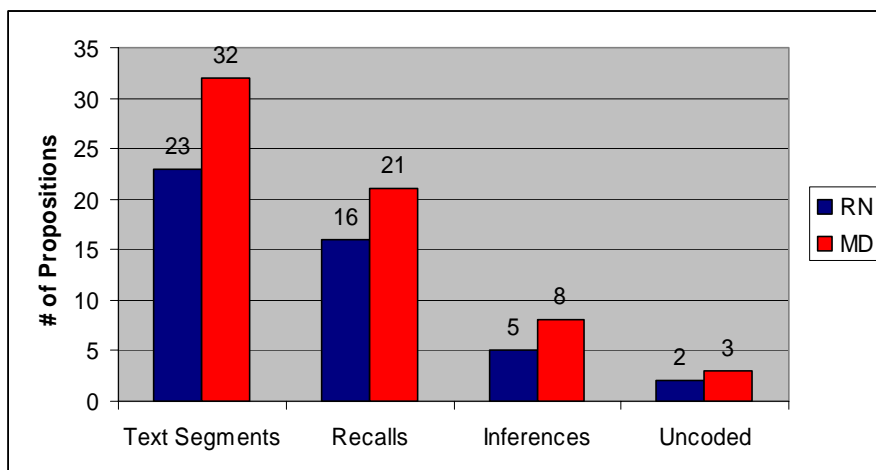
Sample Characteristics

Five registered nurses and 5 physicians consented to participate in this pilot study. Of the 10 subjects, 60% were female and 40% were male. Given that this study sought to determine the feasibility of the methodology, specialty background and expertise were not considered. Additionally, since each subject was asked to review and summarize three cases, and there were 5 subjects per group (physicians and nurses), a total of 30 cases were reviewed and analyzed.

Types of Propositions

The initial propositional analysis of the physician and nurse's summaries revealed no significant differences between mean inferences, recalls, and un-coded information (Figure 2.). However, overall there were on the average more propositions per case in the

Figure 2. Mean number of coded propositions for MDs and RNs.

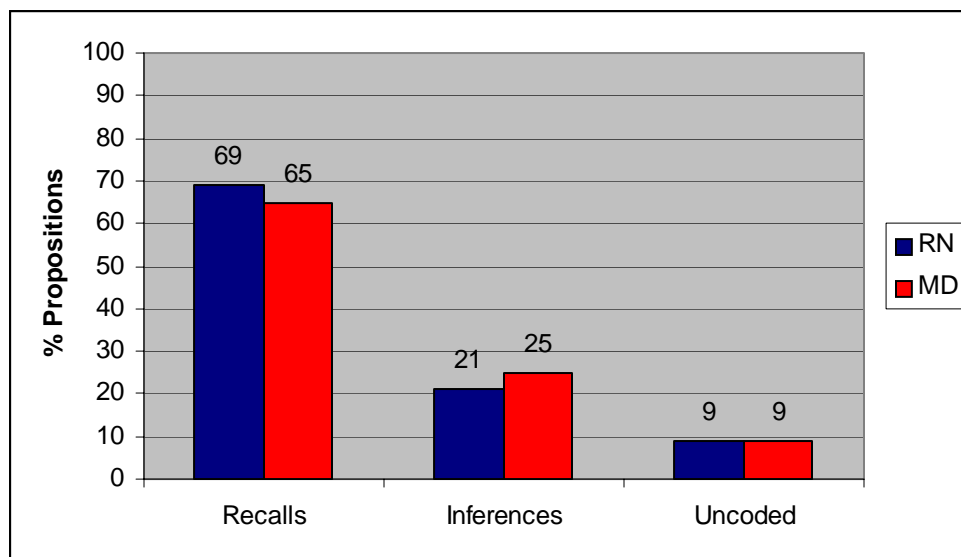


physician's summaries than in the nurse's summaries (32 vs. 23, respectively).

Furthermore the physicians on the average made more recalls (21 vs. 16), more inferences (8 vs. 5), and had on the average slightly more un-coded propositions (3 vs. 2)

than the nurses. In addition the physicians showed only minimal differential performance in terms of the percentage of mean inferences (see Figure 3.) as compared with the nurses, (25% vs. 21%, respectively), and made less recalls in terms of the mean percentage of recalls as compared with the nurses, (65% vs. 69%, respectively). These results are similar to the results previously published where the physicians on the average made more inferences and the nurses made more recalls (Johnson, 2001). The results from the present study suggest that the physicians drew more inferential information from the EMR and processed the information at a more conceptual level, while the nurses recalled more descriptive information from the EMR.

Figure 3. Mean percentages of coded propositions for MDs and RNs



Summary Content

We also analyzed the type of information the subjects included in their summaries. Patient information presented to the physicians and nurses in the contrived electronic medical records was divided into 14 different sections. These are shown in Table 1 along with the percent of the cases, where the respective subjects included some

portion of the patient information provided in each section of the EMR, in their verbal summaries. The main differences shown here were that the physicians were more likely to include past medical history, family history, social history, physical exam findings, and assessments (diagnosis), than the nurses included in their summaries. The nurses provided more information in their summaries on review of systems, and orders/dispositions. Although demographics, history of present illness, physical exam, and orders/dispositions were included in greater than 50% of the summaries by both physicians and nurses, the physicians on the whole provided more information in their summaries. Overall, these preliminary results provide insight on which information was considered more important to each respective practice group and is a reflection of their training in general.

Table 1. Differences in Information Provided in Subject Summaries

EMR Sections	Nurses (n)	Physicians (n)
Demographics	93% (14)	100% (15)
Chief Complaint	47% (7)	47% (7)
History of Present Illness	100% (15)	93% (14)
Past Medical History	27% (4)	47% (7)
Family History	27% (4)	67% (10)
Social History	7% (1)	27% (4)
Habits	7% (1)	13% (2)
Allergies	13% (2)	13% (2)
Review of Systems	73% (11)	33% (5)
Vital Signs	40% (6)	53% (8)
Physical Exam	73% (11)	100% (15)
Assessment	27% (4)	80% (12)
Medications	47% (7)	40% (6)
Orders/Dispositions	87% (13)	73% (11)

Inferences in Summaries

Finally, an analysis of the type of inferences that the physicians and nurses provided in their summaries was evaluated in terms of the content of the inferences and categorized according to the EMR sections. On the whole, the physicians made 120 (25%) inferences from 477 text segments. Of these 120 inferences, 55 (46%) were made

on findings within the physical exam section, 13 (11%) were made on vital sign information, and on history of present illness, respectively. The remainder of the inferences was less than 10% in each of the following sections: past medical and family histories, habits, review of systems, assessments, and medications. However, where only 8% ($n = 9$) of the inferences made by the physicians were in the area of assessments or were of diagnostic character, only 3% ($n = 2$) of the nurses made inferences based on these findings. Similarly, the nurses made the most inferences in the physical exam category, 28% ($n = 19$), 25% ($n = 17$) in the history of present illness category and 10% ($n = 7$) of their inferences were made based upon vital sign information. Once again, the remainder of the inferences was less than 10% in each of the following sections: chief complaint, past medical and family histories, and medications. In contrast to the physicians, nurses made 18% ($n = 12$) of their inferences on the review of systems, while only 5% ($n = 6$) of the physicians made inferences regarding the findings in this section.

Eye Tracking Data

Finally the eye tracking data was analyzed to determine if where the subject focused his/her attention was related to the concepts included in their summaries. Only the eye tracking analog data in 4 summaries of the anxiety case were reviewed. The numbers of fixations were counted and compared with the word counts for each EMR section. Overall, there was no difference between the average number of fixations for both the physicians and nurses. The physicians had an average of 388 fixations and the nurses had an average of 367 fixations. It should be mentioned that although all subjects were allowed to examine and reexamine as many sections of the EMR as they needed, on the average both physicians and nurses reviewed approximately the same number of

sections, 17 and 16, respectively. Since the fixations occurred on words within the text, the navigation fixations (those occurring on the menu) were subtracted and the remaining total number of fixations was divided by the total number of words in the EMR. This was further calculated on a more granular level by the section of the EMR. On the whole, the nurses fixated on an average of 44% of the text, and the physicians fixated on an average of 46% of the text.

Qualitative and Quantitative Differences

These preliminary data suggest that the physicians and nurses' summaries were both quantitatively and qualitatively different. Quantitatively differences were noted between the proportion of recalled vs. inferred propositions among physicians and nurses. However, there were not any significant differences between the amounts of text the physicians and nurses fixated on. Qualitatively, differences were noted on the context of the inferences where physicians made more inferences on the physical exam findings and assessments than the nurses and the nurses made more inferences on the review of systems findings.

Discussion

A feasibility study of combining two different methodologies, talk-aloud protocols (qualitative data) and eye tracking (quantitative data), was evaluated as a process for determining the mental models constructed by clinicians while reading electronic medical records (EMR). This section discusses the significance, limitations, implications and future research directions of this work.

Using verbal protocols such as the talk-aloud technique, with eye tracking techniques generates massive amounts of data. The challenge lies in finding meaning

within the data. The results of this study show eye tracking did not add to the construction of clinician mental models. It is thought that tracking the amount of time subjects spend on reviewing the cases would provide comparable data. However, propositional analysis is a feasible way to assess mental models constructed by physicians and nurses. The results of this study showed that using propositional analysis is a feasible way to assess the mental models constructed by physicians and nurses. The study used an empirical approach to assess the similarities and differences in the mental models of patients constructed by physicians and nurses. Assessing the differences and similarities allowed us to thoroughly examine what information is shared and unshared, included and excluded, and subsequently provided insight into the thinking and reasoning processes of the clinicians. This study indicated that a large-scale prospective study of the mental models of clinicians had the potential to provide useful information. However, the future study will need to specifically control the background of the physicians and nurses to provide more relevant data.

Although this study only analyzed these data in general terms so as to determine the feasibility of using these methods, the results suggest that there are both quantitative and qualitative differences in the mental models of patients constructed by physicians and nurses. Differences were shown in the number of inferences, recalls and un-coded statements between the physicians and nurses, as well as in which information (chunks) were included and excluded and which information was shared vs. unshared. Overall, physicians offered more propositions, inferences, and assessments, and included a greater variety and depth of information in their summaries than the nurses. Although it was expected that there would be differences between physicians and nurses due to divergent

professional goals and theoretical and practice models, the extent of these differences has been unknown. It is thought, as in the expert-novice paradigm, that physicians had less recalls and more inferences because the information provided may have cued the physician's knowledge in more relevant ways. Understanding the mental models of different types of clinicians is merely a part of the process of determining the needs of the clinicians for the EMR just as user and task analyses are only parts of the process.

The eye tracking data did not provide any significant information that complemented the propositional analysis. The difference in the number of fixations between the physicians and nurses did not show any significant differences. Thus eye tracking did not supplement the propositional analysis in determining how physicians and nurses construct mental models.

Limitations

The primary limitation of the study is that the small sample size did not allow computation of statistical significance levels. Nevertheless, the pilot study allowed us to determine the viability of using verbal protocols as a method to determine the construction of mental models before attempting a large-scale study. Furthermore the pilot gave clear direction on how to improve the actual study. As such, the pilot did exactly what it was supposed to do. It demonstrated proof of concept and gave directions for the refinement of the actual study.

There were several other limitations with this design of this pilot study. First, nurses are not generally trained to dictate summaries based on findings, as physicians are trained to do so, thus some of the RN/MD differences might be the result of this confounding variable.

Second, the anagram and math problems for the practice sessions in the verbal protocol were poor choices for this population. It was noted that every subject was more concerned with getting the answer wrong than practicing the technique. This was evidenced by some of the subjects making self-effacing remarks regarding the problem presented. Ericsson and Simon (1984) support this finding. They stated that choosing a warm-up exercise can be difficult and mental multiplication, for example might be too hard for the subjects, thus causing embarrassment. They suggest using addition with 2 or 3 digit numbers and/or asking the subject to find as many words as possible that rhyme with a certain word or provide them scrambled letters and ask them to find as many words as they can within these scrambled letters. This task for teaching subjects on how to talk-aloud should definitely be as simple and non-threatening as possible.

Third, the presented cases should match the background of the practitioners. For example if surgical cases are given, it is suggested to use only surgeons and surgery nurses, or if pediatric cases are given, then only use pediatricians or pediatric nurses. The physicians and nurses that participated in this pilot study were a convenience sample drawn from various specialties. There were problems with this approach. For example, abbreviations used within various specialties in medicine may not be known within all of the specialties. This was true with the pilot study. The abbreviation, GSW (gunshot wound), was unknown to most of the practitioners. In other words, the cases need to match the specialties of the practitioners because too much variability will be introduced and the mental models may not be accurately translated.

Fourth, eye tracking imposed a significant distraction during the study and added a significant amount of time to each experiment. Since the machine had to be

recalibrated on all of the subjects during or at the end of each case reviewed, subjects were interrupted while reviewing the case or frustrated that they had to endure the recalibration procedure again. The imposition of time, subject interruption, and subject frustration needed elimination.

Fifth, fatigue was an issue with the practitioners in the pilot. It appeared that they completed the last case as quickly as possible. It might be better if fewer cases were presented or the length of the cases shortened.

These limitations will be important to address in the large-scale prospective study, since the methodology should impose only minimal demands on the subject in order to obtain accurate and reliable information

Conclusions

A pilot study was conducted to evaluate the feasibility of combining natural language representation, propositional analysis, with eye tracking to understand the development of mental models constructed by physicians and nurses when reading an electronic medical record (EMR). A secondary goal was to assess differences among physicians' and nurses' mental models. Although each methodology produced different types of data, qualitative and quantitative, only propositional analysis uncovered the cognitive processes of clinicians. Analyzing narrative summaries not only provided information on how the text was comprehended, but also revealed what was considered important enough to be distilled, abstracted, and interrelated into one comprehensive whole. Thus using verbal protocols and propositional analysis is a feasible method for assessing mental model construction by clinicians.

Implications and Future Research

The new study will incorporate the following changes:

1. Since nurses are not trained to dictate summaries, they will be given a scenario that matches their practice pattern.
2. The subject's practice exercise in verbal protocols will be simplified by using addition of a 2 and 3 digit number and asking the subject to find as many words as possible within a set of scrambled letters.
3. The presented cases will match the background of the practitioners. Only Gastrointestinal (GI) cases will be created and clinicians with a background in gastroenterology or internal medicine will be recruited to participate.
4. Eye tracking will be eliminated.
5. Since eye tracking has been eliminated, subject fatigue should be lessened because it only took the practitioners approximately ten minutes to review the cases without eye tracking.
6. The future study will additionally increase the number of subjects to allow statistically significant conclusions to be drawn. This pilot study provided a rudimentary insight into how clinicians construct mental models. While there were some problems, the study gave clear direction on how to improve the methodological approaches in the future study.

Current Study

The study presented here evaluates how the different backgrounds and tasks of physicians and nurses interact with different displays of information to affect clinical comprehension and thus, mental models. Specifically, this study examined the effects of clinician background, tasks, and display formats on comprehension. The results of this research will provide insight into the mental models constructed by clinicians and will assist in contributing to the theoretical foundations of interface display design in the medical domain.

Two hypotheses were evaluated:

1. The same information display will lead to different mental models among different types of clinicians.
2. Different displays of the same information will lead to different mental models within the same clinician type.

This research study is a repeated measure nested experimental design, that compares how clinicians comprehend information both within and between clinician types, and that uses verbal protocols to elicit the mental models of patients constructed by physicians and nurses. Propositional analysis was used to construct a text-based model of the patient summaries generated by the clinicians, where idea units were identified and compared. The physicians and nurses were randomized to two cases, one of which had information highlighted and another in which information within the case was not highlighted. Highlighted information within the cases was determined through physician and nurse expert review.

Design

Human Subjects Research Approval

Approval to conduct this study was obtained from the university institutional review board, Committee for the Protection of Human Subjects (Appendix A).

Methods to Elicit Clinician Mental Models

Verbal Protocols and Observation

Verbal protocols such as the talk-aloud technique as earlier reviewed was used to elicit the clinical comprehension and thus, mental models of patients constructed by physicians and nurses. Observation was used to observe the subjects while they completed their tasks of reviewing out-loud and summarizing two presented cases.

Instrumentation

Data for this study were collected in the form of a demographic and data collection form (Appendix B), field notes collected during participant observations, and digital audiotaped verbal protocols. The demographic information, which included gender, age, education, occupation, and years in practice, were collected through a structured interview. The field notes were recorded on the demographic and data collection form. The field notes included the order in which the subject reviewed the cases by section, sections excluded from the subject review of the case, sections that were re-reviewed and any particular difficulties that the subjects experienced with the case.

Case Construction

A total of three gastrointestinal cases were constructed using only fictitious data. No real patient data was used. The diagnoses of the cases were appendicitis, gastroenteritis, and pancreatitis. The mock cases contained 15 main sections and 13 to 14

subsections. The 15 main sections were demographic, history of present illness, histories and habits, current medications, allergies, review of systems, vital signs, input and output, physical exam: eye/ears, nose and throat (ENT)/neck, physical exam: respiratory/cardiovascular/gastrointestinal, physical exam: genitourinary/lymphatic/musculoskeletal, physical exam: skin/neurological/mental status exam, nursing notes, assessment, and initial physician orders. The subsections were within the physical exam sections. The physical exam: eye/ENT/neck contained five subsections; general information, eyes, ears/nose/throat, neck, and breast. The breast subsection was in the gastroenteritis case only. The physical exam: respiratory/cardiovascular/gastrointestinal contained three subsections; respiratory, cardiovascular, and gastrointestinal information. The physical exam: genitourinary/lymphatic/musculoskeletal contained three subsections: genitourinary, lymphatic, and musculoskeletal information. Finally the physical exam: skin/neurological/mental status exam contained three subsections: skin, neurological, and mental status exam. Once these mock cases were constructed, experts were asked to review the cases for content accuracy and for their conception of important sections of the cases that needed to be highlighted for subject review.

Expert Case Reviews

A total of four experts, a gastroenterologist, medical internist, and two medical/surgical nursing faculty, reviewed the gastroenteritis and pancreatitis cases for content accuracy and made corrections as needed. The experts highlighted chunks of information within each case that they individually considered important information for their respective clinician type to note in an assessment of the patient. During their

reviews, the experts knew the diagnosis of the cases. There were differences in the information that was highlighted between the physician and nurse experts. This was assumed in the design phase of the experiment and it was planned to give the physician and nurse subjects the same cases in terms of content, but with different information highlighted. So although the cases were exactly the same in content, they were different for the nurse and physician subjects, in terms of highlighted information. It was assumed that information that may have been important to the physicians might not have been important to the nurses and visa versa.

The physician experts made a total of 13 content changes to the gastroenteritis case and 19 content changes to the pancreatitis case. Content changes included adding information, eliminating information, and changing information. Added information included such items as no hematemesis, nonicteric sclera, chills, and seasonal allergies. An example of excluded information was “good skin turgor”. An example of changing information was increasing the blood pressure and pulse values. Once, the corrections were made to the cases, the cases were compared for agreement between the physician experts and nurse experts respectively for the chunks of information highlighted.

In the gastroenteritis case, the physician experts provided a total of 33 combined items that were highlighted by either both or one of the physician experts, with agreement on 25 (75%) of the highlighted chunks of information (sentences or partial sentences). These 25 chunks of information broke down into 33 highlighted propositions out of a total of 215 propositions. In the pancreatitis case, there were a total of 38 combined chunks of information (sentences or partial sentences) that were highlighted by either

both or one of the physician experts. There was agreement on 28 (74%) chunks of information, which broke down into 51 propositions out of 276 propositions.

Once the cases were changed for content accuracy, there was a second review by the nurse experts for content accuracy, who offered no additional comments. They additionally highlighted chunks of information within the pancreatitis and gastroenteritis cases for importance to the nursing care of the patients. The nurses did not make any further content changes for accuracy. In the gastroenteritis case, both nurse experts highlighted a combined total of 67 chunks of information. There was agreement upon 35 (52%) chunks of information, which broke down into 52 propositions out of a total of 215 propositions. In the pancreatitis case, the expert nurses highlighted a combined total of 103 chunks of information, but there was only agreement on 57 (55%) chunks of information. These 57 chunks of information broke down into 67 propositions out of 276 propositions.

The differences in the highlighted cases between the physician and nurses showed that on average the physician experts highlighted 17% of the propositions and the nurse experts highlighted 24% of the propositions within the pancreatitis and gastroenteritis cases. Although the physician experts highlighted less information than the nurse experts there was some agreement on highlighted information within the cases. For example in the pancreatitis case, the physician and nurse experts agreed upon 49% of the information they highlighted, and in the gastroenteritis case, the physician and nurse experts agreed upon 39% of the information they highlighted. Differences were expected due to differences in practice models.

Only the information that was in agreement within the nursing experts was included in the nursing cases and only the information that was in agreement within the physician experts was included within the physician cases. The differences within the nurse and physician experts were not considered to have significant consequences to the outcome of the study, since we are examining differences in displays affecting comprehension and not differences in content. Combining expert opinions to achieve an average representation is considered an acceptable method as long as there are not consequences to the outcome of the study (Morgan & Henrion, 1990). There were a total of three different displays and within each group, two different displays. For example, there were the non-highlighted pancreatitis and gastroenteritis cases where the case content was exactly the same for the physicians and nurses. However, there were the highlighted nursing cases and the highlighted physician cases which differed only in terms of highlighting, the case content was exactly the same. This had to be done for practical reasons. Physicians and nurses according to their individual practice models consider the same yet different types of information important. See Appendix C and D for examples of differences in highlighting between the physicians and nurses.

Experimental Case Display

Once the cases were formalized for subject review, the cases were inserted into Microsoft Access and formatted for ease of subject review. Figure 5 shows a screen shot of the physician highlighted pancreatitis case, history and habits section. Each case was divided into 15 main sections, as earlier described, with each section represented on a separate page or form. Navigation through the sections could easily be accomplished through labeled buttons on the left side of the screen. Additionally on the bottom of the

screen, there was a pull-down menu for case choice. Once the case was chosen, the screen configuration allowed the subjects to easily navigate through the case in any order they chose to follow. For example, if the subjects were reviewing the demographics section and wanted to review the physician orders section next, they could click on the physician orders button and the text in the right window would show that information. All of the cases for both the physicians and nurses were set up in Microsoft Access in the same fashion.

Figure 5. Pancreatitis highlighted case: history & habits

Microsoft Access - [frmMain : Form]

File Edit View Insert Format Records Tools Window Help

Tahoma 10

Demographics

HPI

History/Habits

Medications

Allergies

Review Of Systems

Vital Signs

Input/Output

PE: Eye/ENT/Neck

PE: Resp/CV/GI

PE: GU/Lymph/MSK

PE: Skin/Neuro/MSE

Nursing Notes

Assessment

Physician Orders

Done

Select Patient

Case 1HL

HISTORIES/HABITS

Past Medical History
Childhood asthma
Mild hypertension
Gastritis

Family History
Father MI at age 53

Social History
Employed as a painter
Divorced with 2 sons, ages 22 and 24
Lives alone

Habits
Tobacco: cigarettes 2 ppd
Alcohol: one 6 pack of beer/day & 1/5 whiskey/day on the weekends
Drugs: denies

Form View

Subject Randomization

Prior to subject recruitment the order of the case formats that were to be presented to the physician and nurse subjects was determined through randomization and counterbalancing. Counterbalancing was used to control for effects due to the order of

presentation. Initially, a spreadsheet in Microsoft Excel was created with 48 successive accession numbers for the physicians and nurses, respectively. The four potential display orders were then entered 6 different times for each of the 24 physician and 24 nurse subjects. These four potential display orders were:

Pancreatitis Non-highlighted, Gastroenteritis Highlighted

Gastroenteritis Highlighted, Pancreatitis Non-highlighted

Gastroenteritis Non-highlighted, Pancreatitis Highlighted

Pancreatitis Highlighted, Gastroenteritis Non-highlighted

For each respective group, the cases were then assigned a randomized number using the (rand) function within Microsoft Excel. These randomized numbers were then sorted with the cases and associated accession numbers in ascending order. This process ensured a randomization of the cases that the subjects were assigned to by successive accession number.

Methods

The primary aim of this study was to determine the relationship between displays presented to clinicians and the clinical comprehension and thus, mental models constructed by the clinicians. Both hypotheses 1 and 2 were tested through the use of observation and the talk-aloud technique (Ericsson & Simon, 1984) using digital videotaping to audio-tape the subjects verbalizations of each case.

Sample and Setting

This study solicited a purposeful sample of 48 subjects consisting of 24 practicing registered nurses and 24 practicing physicians within the greater Houston/Galveston area. Subjects were recruited through advertisement (Appendix E) and formal and informal

presentations. Subjects were recruited regardless of ethnicity and gender; however, all were over the age of 21. Participants were given \$50.00 as compensation for their participation in this research. Only practicing gastrointestinal medicine/internal medicine physicians and registered nurses were recruited to participate. Non-English speaking was the only exclusion criteria due to potential variance in comprehension induced by linguistic factors. Women were equally included in this research study. No one was excluded based upon ethnicity or gender. Due to concerns regarding problems with recruitment and time concerns, practice years of the subjects were not considered during recruitment and thus were considered a delimitation. All subjects were required to give signed informed consent (Appendix F).

The study was conducted in a private quiet room at the University of Texas Health Science Center at Houston, School of Health Information Sciences or in the private offices of individual clinicians, using a laptop computer. Both settings allowed the subjects to talk out-loud as they read, interpreted, and summarized the medical cases in an undisturbed setting allowing for no breaches in subject confidentiality. The subject's verbalizations were audiotaped. The subject's faces were not videotaped.

Experimental Procedure

Once the subject agreed to participation, an amenable date and place to perform the experiment was arranged with the subject. Prior to the beginning of the experiment, the subject was informed again of the purpose of the research and potential risks of the research. The only known potential risk to the subjects was breach of confidentiality. This was not considered to present any significant risk. All subject information was coded using a study accession number. All links to subject identification were destroyed

after all data was collected. Only coded de-identified data was used in data analysis. No incidents were reported to the Committee for the Protection of Human Subjects at the University of Texas Health Science Center at Houston.

The subject was asked to read the informed consent and the primary investigator addressed all concerns and questions. Once all questions were addressed, the subject signed two copies of the informed consent. The subject was given one copy of the signed informed consent form and the other copy was kept in a locked file cabinet.

Subjects were informed that they would be given one gastrointestinal training case to learn how to navigate through the cases and understand the structure of the cases and two gastrointestinal test cases to review and summarize. They were informed that once they finished their review of each case they would need to summarize the case as they normally would to a colleague. They were given the following scenario:

“A patient has just been admitted to the general medicine unit. Although you have not seen the patient, you only have time to review the record before you give a summary of the patient to the oncoming nurse or on-call physician (as appropriate per subject). If there is any additional things that the on-coming physician or nurse needs to attend to, you should include this in your summary.”

They were additionally instructed that there were no right or wrong answers and that I was not testing, nor judging their skills as a clinician. Again, they were told that they would be asked to talk-aloud as they reviewed, analyzed, and summarized each case on the computer screen. They were given the following instructions regarding the talk-aloud technique.

“Using the talk-aloud technique means that I would like you to say out-loud everything that you are thinking or would normally say to yourself silently. Just act as if you are alone in the room speaking to yourself. If you are silent for any length of time, I will remind you to keep talking aloud. Everything you say out-loud will be recorded onto the audio track of videotape.”

After these instructions, the subjects were given two problems to practice talking-aloud. The first problem was adding out-loud 156 and 85. The other problem was to make as many words as possible from the following scrambled letters: edrcldhma.

Finally, they were reminded again, that after they finished reviewing each case, they would need to give their summary of the case to another clinician. They were additionally informed that they would not be able to look back at the case and would need to summarize the case from memory. They were informed that their faces would not be videotaped and all verbal information would be kept confidential and would only be identified through an accession number. Only aggregated data would be published.

The subject was then assigned to a sequential accession number, which was associated with one of the randomized case presentations. Once the subjects were trained with the first appendicitis case, they were then instructed to choose the first particular case that they were randomized to. Subjects were presented with either the gastroenteritis highlighted or non-highlighted case or pancreatitis highlighted or non-highlighted case. The nurses only reviewed the highlighted cases that were highlighted by the nurse experts and the physicians only reviewed the highlighted cases that were highlighted by the physician experts. The highlighted formats represented concepts within the case that were considered important to the physicians’ and nurses’ to carry out their respective tasks of

caring for the patient. The non-highlighted cases were exactly the same for both groups of clinicians. After each subject reviewed each case, the subject was then asked to summarize the case without looking back on the text, according to his or her practice model. All of the cases were presented on a computer screen as earlier outlined. While the subjects reviewed the cases, field notes earlier described were taken on all subjects. Only the subject's verbalizations were recorded. This allowed comparisons within and between subjects on each presented case.

Once the subject completed his or her review and summary of both cases they were given either \$50.00 or a gift certificate for \$50.00 as compensation for their participation. The compensation pay of \$50.00 or a gift certificate for \$50.00 was set based upon the prior experiences with the pilot study conducted at The University of Texas Health Science Center at Houston, School of Health Information Sciences (Johnson, Johnson, Patel, & Turley, 2002; T. R. Johnson, Patel, & Turley, 2001). This study, which examined the differences in mental models constructed by physicians and nurses, albeit through a different methodology, offered compensation of \$50.00 to the physicians and nurses for their participation. The clinicians were comfortable with this level of compensation, but had different views of the compensation. Three out of five of the physicians suggested waiving the compensation, and the nurses were content with the amount. The pilot study took approximately one hour to complete. Based upon this previous experience, it was determined that the \$50.00 or a gift certificate for \$50.00 was adequate as compensation.

Potential Benefits of the Proposed Research to Subjects

There were no direct benefits to the subjects participating in the study other than the \$50.00 gift certificate.

Experimental Difficulties

There were no significant difficulties with any of the experimental procedures including subject recruitment.

Data Collection and Analysis

All data were collected and coded by accession number. No identifying information was associated with the collected data. All data were entered into an electronic database with key fields. The backend of the database was in Microsoft Access. The database was password protected. All subject identifiers were removed and only the accession number of the subjects was entered into the database. All paper forms and audiotapes connected with the study were stored in a locked filing cabinet in a locked office.

The initial data entered into the Microsoft Access database included all demographic information, field notes, case time, and quantitative propositional information. Once these data were entered, the digital audio recordings of the subject's summaries were transcribed into a Microsoft Word text file. These summaries yielded over 37 pages of single-spaced typed transcriptions, 14 pages of nursing summary transcriptions and 23 pages of physician summary transcriptions. Once the summaries were transcribed, a propositional analysis was conducted. After the propositional analysis was completed, the number of propositions, and the type and number of the coded propositions such as recalls, inferences, assumptions, negatives, errors,

conditionals, and interventions were entered into the database. Furthermore, the number of the propositions that were highlighted were also entered into the database.

Propositional Analysis

The original cases were first broken down into sentences or sentence segments since not all of the information in the original cases was in a sentence format. These sentences or sentence segments were numbered sequentially. These sentences were then broken down into idea units or propositions. The original cases were broken down as such for comparison with the clinician summaries.

The original text of the physician and nurse summaries was then broken down into sentences and these sentences were sequentially numbered within each summary. The numbered sentences were then broken down into propositions or idea units maintaining a numbering sequence as a reference for later use. The following example shows that this is proposition #1 within sentence #32 of the subject's summary.

32.1 He has some tremors,

This is useful for determining causal relationships or drawing cognitive maps for analysis. The propositions of the subject summaries were matched against the original text and the segments coded. Categories were used to encode these data. Analysis additionally included which information chunks (propositions) were shared vs. unshared among the participants. The propositions were analyzed to determine which relevant or irrelevant information was included in the summaries. Relevance was determined by the percentage of the participants who included particular chunks of information in the summary. Only propositions included by $\geq 50\%$ of the subjects were considered in the

conceptual graphs of the summaries. The time a subject took to read the content was also examined.

Text Segment Coding

The text segments were coded as recalls, inferences, negatives, assumptions, conditionals, interventions, or errors. The propositions were further coded for the section from the mock medical record they were derived from, and whether that proposition was highlighted in the original text. Finally, all propositions were coded for concept. For example, the proposition, "He has some tremors", was coded as tremors. In other words, each proposition was given one conceptual unit.

Originally, the plan was to code the propositions only as inferences, recalls, or uncoded information. However, as the propositions were read and reread, consistent patterns began to emerge from these data and the data-coding scheme expanded to include recalls, inferences, assumptions, negatives, interventions, conditionals, and errors. Miles and Huberman (1994) describe this data reduction process as a way to classify, direct, remove, and categorize these data so that definitive conclusions can be made. Tesch (1990) calls it data condensation. This pattern coding provided a more accurate and complete picture of the summaries. Through an iterative review of these data all of the patterns led to the current coding scheme. The definition of the recalls and inferences has been described. The definitions of the other five coding schemes that emerged from these are now described.

An assumption was defined as a statement that is stated as true without having a proof given for it (Angeles, 1992). Negatives were defined as statements of denial (Angeles, 1992). Conditional statements were defined as the development of an

argument, such as “if x, then y” (Angeles, 1992). Interventions were defined as what the physician or nurse does vis-à-vis the patient such as prescribing tests, medications, procedures, etc. Finally, errors were defined as a departure from the truth or incorrect information. Table 2 shows an example of different types of propositions and their associated codes.

Table 2. Examples of Coding Scheme

Propositions	Code
32.1 He has some tremors,	Recall
53.1 Patient may simply have gastritis.	Inference
3.1 She did not have any surgical history	Assumption
12.1 Surgical history not given.	Negative
21.1 If his LFT's seem to be increasing then, ...	Conditional
59.1 We will get an ultrasound of the right upper quadrant	Intervention
5.1 She denies temperature.	Error

Once the propositions were coded, these data were iteratively reviewed and recoded until there was consistency within the coding scheme for all of the cases. The propositions were further coded when possible for the section of the mock medical record they were drawn from, such as the history of present illness, current medication, etc. All recalls and inferences were consistently coded for the section that they were drawn from, but it was not possible to consistently code the assumptions, interventions, negatives, conditional statements or errors because these propositions were not part of the original mock medical record.

The propositions were then compared with the original cases and were coded as being highlighted in the original case or non-highlighted. This allowed comparisons between and within clinician types for proportion of highlighted information given in the summaries.

After the propositions were coded for section, each proposition was given a conceptual code that directly related back to the proposition. There were meaningful, repetitive concepts within the breakdown of the summaries. These patterns were identified through another iterative review of these data. Once the concepts were developed, these data were iteratively reviewed for consistency of coding until saturation occurred. Saturation was defined as the point in which no new concepts were conceived from these data and all data were conceptually consistently matched. Table 3 shows examples of the concepts; Can't Eat, Tremors, and Alcohol. The only type of proposition that was not coded for conceptual information was the errors.

Table 3. Conceptual Examples by Occupation

Proposition	Concept	Occupation
2.1 Very little ability to tolerate oral input over the preceding 48 hours.	Can't eat	MD
4.1 He is unable to eat,	Can't eat	RN
23.5 and tremulous,	Tremors	MD
3.1 He's got tremors	Tremors	RN
20.2 occasional alcohol drinker,	Alcohol	MD

6.2 and he drinks a 6 pack Alcohol RN
of beer/day

Statistical Considerations

The primary analyses were the comparison of within clinician responses and between clinician responses comparing several different independent variables within and between the four cases. The independent variables were occupation and case display type such as highlighted or non-highlighted cases. The dependent variables were the propositional types and time. Table 4 shows the 4 x 4 table depicting the repeated measure nested design. There were 24 subjects per group (24 nurses and 24 physicians) who reviewed two cases each for a total of 48 cases per group or 96 cases total. However, since there were four different cases, only 12 subjects per group were randomized to each case type as shown in Table 4.

Table 4. Repeated Measure Nested Design

	RN	RN	MD	MD
Pancreatitis	12		12	
Pancreatitis HL*		12		12
Gastroenteritis		12		12
Gastroenteritis HL*	12		12	

HL = highlighted case

Descriptive statistics and box plots were initially applied to characterize the distribution of the observations of all of the aggregated data. Descriptive statistics were also applied to all of the demographic information, the sectional information, time

information, and propositional type information. An analysis plan for testing both Hypothesis 1 and Hypothesis 2 can be reviewed in Appendix G.

Hypothesis 1 which states that the same information display creates different mental models among different clinicians was tested with a between groups comparison. This between groups comparison was stratified by case and was made between physicians and nurses summarizing each of the following cases; gastroenteritis non-highlighted, gastroenteritis highlighted, pancreatitis non-highlighted, and pancreatitis highlighted. The independent variables were occupation and case and the dependent variables were time to complete the review and summary of each case, recalls, inferences, assumptions, interventions, negatives, conditionals, errors, total number of propositions, and number of highlighted propositions. All of these dependent variables were continuous variables. A MANOVA was used to test for statistical significance between the groups for each case, using the General Linear Model within SPSS. The analysis was paired with 12 subjects per group per case. Since the mean number of propositions was significantly higher for the physicians than for the nurses, the means of the relative frequencies for the dependent variables were also compared for statistically significant differences between the groups. Descriptive statistics were also used to compare the differences between clinicians regarding the sources of their information, specifically which section of the medical record their summary data were inferred or recalled from and their conceptual differences and agreements between the cases. The analysis of the concepts included only those concepts that were included by $\geq 50\%$ of the physicians and $\geq 50\%$ of the nurses. The shared and unshared concepts were compared.

Hypothesis 2 which states that different displays of the same information will lead to different mental models for the same clinicians was tested with a within group comparison. The comparisons were made between the gastroenteritis non-highlighted and gastroenteritis highlighted cases and pancreatitis non-highlighted and pancreatitis highlighted cases. The independent and dependent variables were exactly the same as in hypothesis 1 using MANOVA to test for significance. Descriptive statistics were also used to compare the differences within clinician type regarding the sources of their information, specifically which section of the medical record their summary data were inferred or recalled from and their conceptual differences and agreements between the cases. The analysis of the concepts included only those concepts that were included by $\geq 50\%$ of the physicians and $\geq 50\%$ of the nurses, respectively. The shared and unshared concepts were compared within the group of physicians and within the group of nurses.

Sample Size

The hypotheses in this study are considered two-tailed hypotheses since the hypotheses imply that there is an association between information displays within and between types of clinician, but the direction of the association is not specifically specified. Based on the previous pilot studies in this area, mean time to complete the cases as to define the sample size needed to detect a difference between nurses and doctors with 80% at a 5% significance. Taking all of these factors into consideration, a total of 24 subjects per group were estimated as an adequate sample size.

Summary

The results of the pilot study showed that verbal protocols such as the talk-aloud technique and the analysis technique of propositional analysis as feasible methods to

understand the development of mental models of patients constructed by physicians and nursing when reading a strictly text based mock electronic medical record. Additionally as a result of the pilot study we determined that eye tracking did not meaningfully add to our understanding of mental model development and thus was excluded from the final research study plan. As such, the final results of the pilot directed the methods and research plan for the current study.

This research study was a repeated measure nested experimental design, that compared how clinicians comprehended different displays of information both within and between clinician types, and that used verbal protocols to elicit the mental models of patients constructed by physicians and nurses. Propositional analysis was used to construct a text-based model of the patient summaries generated by the clinicians, where idea units were identified and compared. A total of 24 physicians and 24 nurses were randomized to two cases, one of which had information highlighted and another in which information within the case was not highlighted. Data reduction of the verbal protocols caused an expansion of the original data-coding scheme from inferences, recalls, or uncoded to inferences, recalls, assumptions, negatives, interventions, conditionals, and errors. This new methodology enabled a more accurate and complete picture of the summaries and thus expanded the current methodology of coding clinical summaries as a means of understanding clinical comprehension.

ANALYSIS OF DATA

The purpose of this study was to determine if the interaction between clinician background and factors in the display of information affected clinician comprehension of patients and thus mental models constructed by the same and different types of clinicians. Two hypotheses were evaluated. One, the same information display will lead to different mental models among different types of clinicians. Two, different displays of the same information will lead to different mental models within the same clinician type. The results of this research provided insight into how these factors affected clinician comprehension. This chapter presents the findings of this research.

Sample Selection and Demographic Characteristics

This study solicited a purposeful sample of 48 subjects consisting of 24 practicing registered nurses and 24 practicing physicians within the greater Houston/Galveston area. The practice specialty was limited to gastrointestinal medicine and internal medicine. Of the 48 subjects, 19 (40%) were male and 29 (60%) were female. The mean age of the subjects was 41.00 ± 10.02 years with a range of 26 to 61 years old. Within the demographic data only, the mean practice years and range of practice years was separated within the physician group to note the differences between the residents and attending physicians. However, these data were not further stratified in the remainder of these data analyses since the subgroups would have been too small to show statistical significance. Table 5 shows the details of the demographic information for both groups.

Table 5. Demographics of All Subjects

Demographics	RN	MD
Male	1 (4%)	18 (75%)
Female	23 (96%)	6 (25%)
Average Age	45.41 \pm 7.45	36.39 \pm 10.34
Range	28 - 60	26 - 61
Associates Degree	7 (29%)	
Diploma Degree	4 (17%)	
Bachelors Degree	10 (42%)	
Masters Degree	3 (12%)	
MD Degree		24 (100%)
		(Attendings) ^a
Average Practice Years	20.62 \pm 7.35	11.00 \pm 10.06
Range	5 - 32	1 - 29
		(PGY) ^b
Average Practice Years		3.58 \pm 1.58
Range		1 - 6

^a Attendings = physicians in practice

^b PGY = resident physicians

In the physician group, 75% of the subjects were male and in the nurse group, 96% of the subjects were female. Interestingly, this distribution is very similar to the national gender distribution of physicians and nurses. Nationally, 76% of the physicians are male and 94% of the nurses are female (AMA, 2003). Although the age ranges of all of the subjects were similar, the nurses on the average were older than the physicians, 45 years old vs. 36 years old, respectively. There was also dissimilarity in the range of practice years for the physicians and nurses. The nurses had a greater mean number of

practice years than the attending physicians, 20.62 ± 7.35 versus 11.00 ± 10.06 , respectively.

Review of Cases: Section and Time Comparison

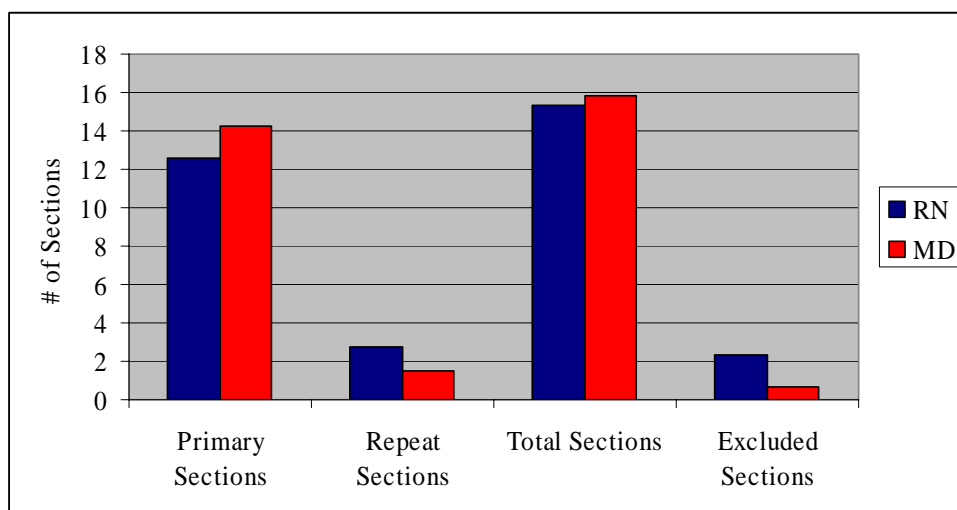
As previously mentioned each case was divided into 15 main sections and within each main section, there were 13 subsections. As the subjects reviewed the cases, the order of their review, the specific sections included or excluded in their review of the cases, and the total time of their review of the cases was noted.

The order the physicians and nurses reviewed the sections of the cases varied by clinician type. Greater than 60% of the physicians reviewed the case sections in the order it was presented to them. The nurses, however, varied their order more often. Although greater than 60% of the nurses reviewed the first three sections in the order presented to them, less than 50% continued the review in this order. No particular pattern was noted in their order of review and was extremely variable by subject.

The sections the subjects examined as they reviewed each case were noted during the experiment. Figure 6 shows the differences between the groups in the mean number of primary sections reviewed, the mean number of sections re-reviewed, the mean number of sections excluded during their review, and the total mean number of sections examined during their review of each case. Primary section was defined as a section the clinician reviewed at least once. Repeat section was defined as a section that a clinician previously reviewed, and later returned to. Total number of sections included all of the primary and repeated sections reviewed. Excluded sections were defined as those sections that were never reviewed. A one-way ANOVA revealed a statistically significant difference between the physicians and nurses ($p = 0.002$) in the number of

primary sections the subjects reviewed in all of the cases combined. The physicians on the average reviewed 14.29 ± 1.70 of the 15 primary sections, whereas the nurses reviewed on the average 12.60 ± 3.23 sections. Although there was not a statistically significant difference in the sections that were repeated for review or in the total number of sections reviewed between the physicians and nurses, the nurses on the average repeated a review of 2.75 ± 4.30 of the sections and the physicians repeated a review of 1.50 ± 2.06 . The repeated review of the sections increased the total mean number of sections reviewed for both groups, so the total number of sections reviewed was not statistically significant between the groups. The nurses reviewed a total mean number of 15.37 ± 5.92 sections and physicians reviewed a total mean number of 15.81 ± 2.68 sections. As expected, since there was a difference in the number of primary sections reviewed, there was a statistically significant difference ($p = .002$) in the number of sections excluded between the groups. On the average, the nurses excluded a mean number of 2.35 ± 3.24 sections and the physicians excluded a mean number of 0.70 ± 1.70 sections.

Figure 6. Mean sections reviewed between physicians and nurses



Of the excluded sections, there were some interesting results. Table 6 shows the number of subjects who did not review the section. These results showed that 33% of the nurses did not review allergy information, 29% did not review medication information, 25% did not review intake and output and history and habits, 12% did not review physician orders and vital sign information, and finally, 8% did not review the nursing notes. In the physician group, 25% did not review the assessment information, 12% did not review the allergy information or the physician orders, and on the average nearly 7% did not review the entire physical exam information. The subgroup that did not review the entire physical exam, did review the respiratory, cardiovascular, and gastrointestinal information.

Table 6. Excluded Sections by Subject

Excluded Section	MD Subjects N (%)	RN Subjects N (%)
Allergy	3 (12.50%)	8 (33.33%)
Assessment	6 (25.00%)	4 (16.67%)
Demographics	1 (4.17%)	0 (0.00%)
History & Habits	1 (4.17%)	6 (25.00%)
History of Present Illness	0 (0.00%)	4 (16.67%)
Intake & Output	5 (20.83%)	6 (25.00%)

Excluded Section	MD Subjects N (%)	RN Subjects N (%)
Medications	1 (4.17%)	7 (29.17%)
Nursing Notes	0 (0.00%)	2 (8.33%)
^a PE: Eyes, Ears, Nose, Throat, Neck, Breast	2 (8.33%)	10 (41.67%)
^a PE: Genitourinary, Musculoskeletal, Lymphatic	2 (8.33%)	8 (33.33%)
^a PE: Respiratory, Cardiovascular, Gastrointestinal	0 (0.00%)	6 (25.00%)
^a PE: Skin, Neurological, Mental Status	1 (4.17%)	10 (41.67%)
Physician Orders	3 (12.50%)	3 (12.50%)
Review of Systems	1 (4.17%)	7 (29.17%)
Vital Signs	0 (0.00%)	3 (12.50%)

^a PE = physical exam

Although there were other exclusions in both groups, these findings were considered the most important since these sections are considered important to the practice models of each group respectively. For example, since the nurses are the primary administrators of all ordered medications, it is not only important for them to

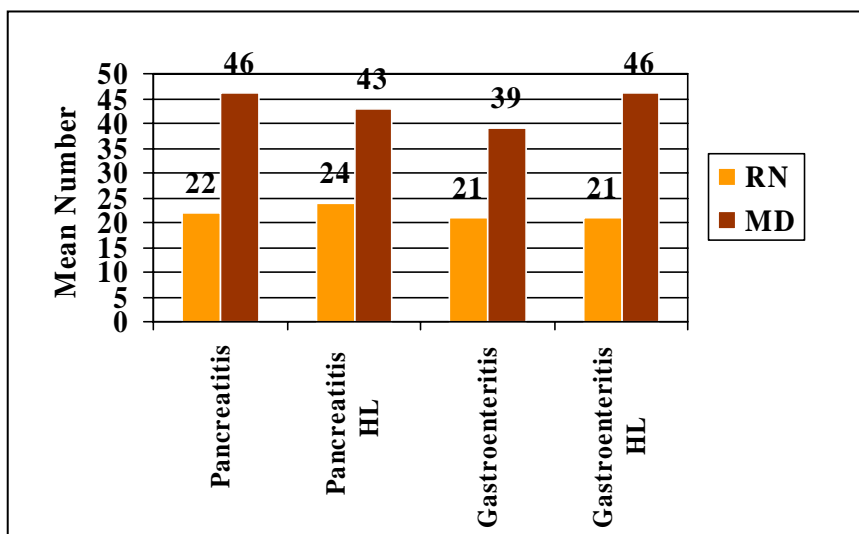
review the medication section and the allergy section, yet 33% of the nurses did not review the allergy information and 29% did not review the medication section. It was not within the scope of this study to research why the excluded sections were not reviewed and so it is unknown specifically why particular individuals within each group skipped certain sections in their review.

Comparison of RN and MD Summaries

The subjects were asked to review and summarize two cases. There were 24 subjects per group (physicians and nurses), so a total of 96 case summaries were reviewed and analyzed. After the subjects reviewed each case, they were instructed to summarize the cases from memory. They were not allowed to reexamine the cases during their oral summary of the cases. Only the summaries of the cases provided by the subjects were transcribed. These summaries yielded over 37 pages of single-spaced typed transcriptions, 14 pages of nursing summary transcriptions and 23 pages of physician summary transcriptions. Once the cases were transcribed, the sentences of each case were divided into text segments or propositions. These propositions were then coded as earlier explained. Overall, there were a total of 3153 propositions for all of the cases, 2089 propositions in the physician cases and 1064 propositions in the nurse cases.

On the whole, there was a statistically significant difference by one-way ANOVA ($p < .001$) between the mean number of propositions generated per case in the physician summaries (43.52 ± 25.55) than in the nurse summaries (22.16 ± 10.62) and thus, the physicians on the average took more time to complete their review and summary of each case as compared to the nurses. Figure 7 shows the mean number of propositions per case.

Figure 7. MD & RN propositional differences among all cases



A one-way ANOVA showed a statistically significant difference ($p = .001$) in the time the two groups of subjects took to review and summarize each case. The nurses on the average took 6.97 ± 3.15 (range = 3 - 20) minutes, whereas the physicians took an average of 9.56 ± 4.10 (range = 5 - 22) minutes to review and summarize each case. However, there was not a statistical difference within each group in the amount of time the two groups of subjects took to review and summarize the highlighted versus the non-highlighted cases. The nurses took an average of 7.08 ± 2.99 minutes to review the highlighted cases and 6.87 ± 3.36 minutes to review the non-highlighted cases. The physicians took an average of 9.54 ± 4.01 minutes to review the highlighted cases and 9.58 ± 4.29 minutes to review the non-highlighted cases.

Overall the physicians generated twice as many propositions than the nurses so in order to make accurate comparisons between the cases the relative frequencies of the propositional types were compared both between and within the groups of clinicians. A review of the relative frequencies of the propositional types in all four cases showed that the frequency distribution was nearly the same within the highlighted cases and within

the non-highlighted cases. For example, in the nursing summaries, 70% to 82% of their propositions were recalls, and in the physician summaries, 40% to 42% of their propositions were recalls. Appendices H – K shows the differences in the mean number and relative frequencies of the propositional type by case. Additionally, the statistically significant differences in propositional types were the same for all four cases. These are shown in appendices L – M. The physicians generated a statistically larger proportion of inferences, interventions and conditional statements than the nurses, whereas the nurses generated a statistically larger proportion of recalls than the physicians. For this reason, the content of the cases was considered unimportant and only the display of the cases was considered for the statistical analysis, thus the cases were combined to compare only highlighting versus non-highlighted cases. This changed the design into a 2 x 2 repeated measure nested design. Table 7 shows the change in the design.

Table 7. A 2 x 2 Repeated Measure Nested Design

	RN	MD
Non-highlighted	24	24
Case		
Highlighted Case	24	24

The comparison on the amount and type of propositions in the remainder of this analysis both within and between subject groups were thus compared only for the display types, highlighted versus non-highlighted cases. However, the conceptual comparisons both within and between the groups were made by both case content and display type.

Differences between Clinicians with the Same Information Display

I have hypothesized that the same information display will lead to different mental models among different clinicians due to their different background and training. The results of the propositional analysis of the summaries revealed some significant differences between the physicians and nurses. Using occupation and display type as the independent variables, differences were examined for the time to complete the case, the number of propositions, types of propositions, amount of highlighted versus non-highlighted propositions, and conceptual differences.

Comparison on Amount and Types of Propositions per Highlighted versus Non-highlighted Cases

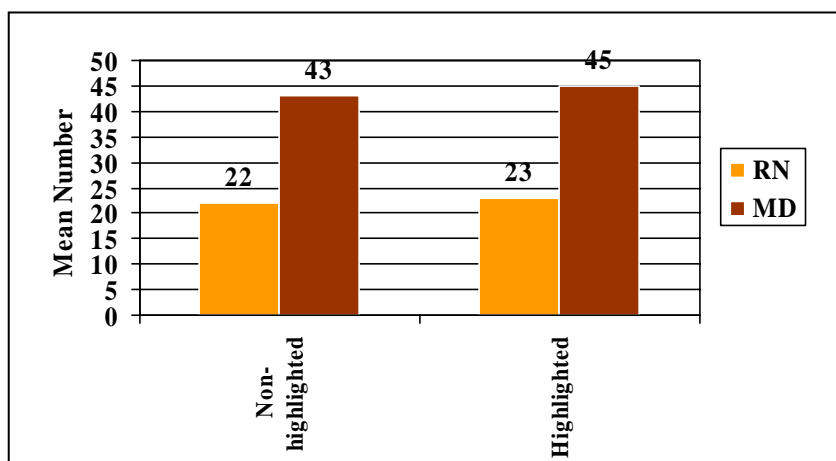
Differences between the clinicians were found in each of the four case displays using MANOVA (general linear model, repeated measures). These differences will be reviewed by case display. A total of 24 nurses and 24 physicians were randomized to a highlighted case and a non-highlighted case. The analysis of the summaries revealed a host of differences between the nurses and physicians.

Upon examining the differences in the propositions included in the summaries of the nurses and physicians, differences were found between the mean number of propositions, the proportion of propositional types, and the proportion of inclusion of highlighted vs. non-highlighted propositions. Although conceptually, there were some similarities between the physician and nurse summaries, there were differences as well.

An examination of the mean number of propositions included in the highlighted versus the non-highlighted summaries showed that the physicians had a larger mean number of propositions per case type than the nurses ($p = < .001$). Figure 8 displays the

mean number of propositions generated by the physicians and nurses by case display type.

Figure 8. MD and RN propositional differences



As expected the time differences between the physicians and nurses ($p = .001$) was reflected by their average number of propositions. Whereas the nurses on the average generated less propositions than the physicians, they took an average of 7 minutes to summarize the non-highlighted and highlighted cases, however, the physicians who generated more propositions than the nurses, took an average of 10 minutes to summarize the non-highlighted and highlighted cases.

The types of propositions included by the physicians and nurses in their summaries differed in four out of the seven propositional types. Figures 9 and 10 show the differences between the physicians and nurses in their summaries of the highlighted ($n = 48$ cases) versus non-highlighted cases ($n = 48$ cases). In both display types, there were statistically significant differences in the relative frequencies of the recalls, inferences, interventions, and conditional statements. There were no statistically difference between the relative frequency of errors, assumptions and negative statements between the physicians and nurses in both case displays.

Figure 9. MD & RN propositional differences in highlighted cases

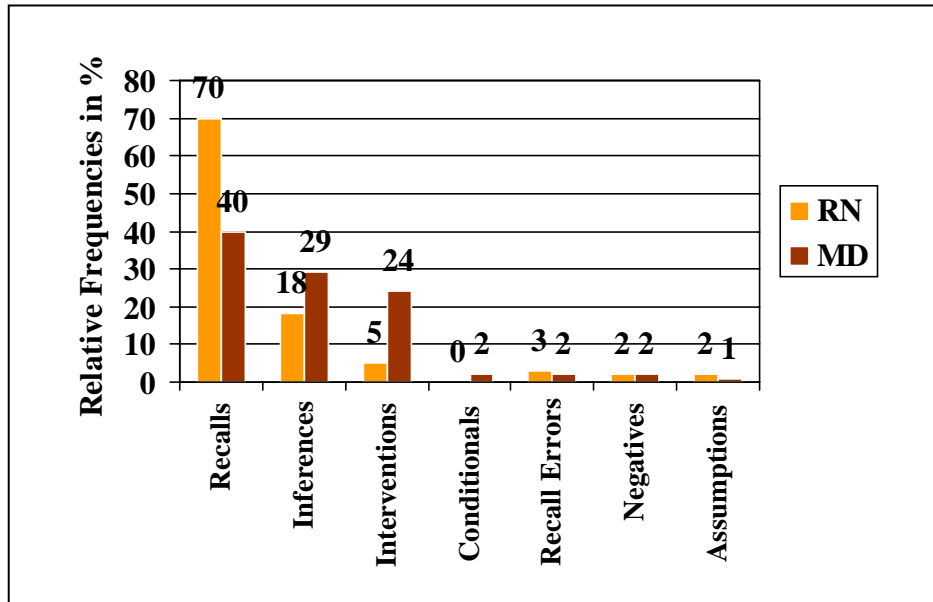
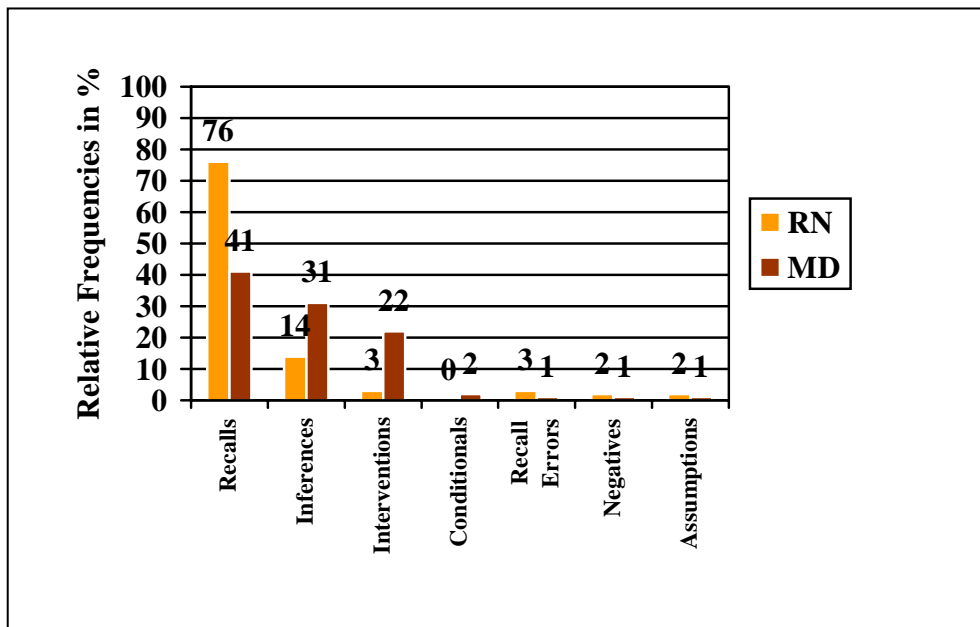


Figure 10. MD & RN propositional differences in non-highlighted cases

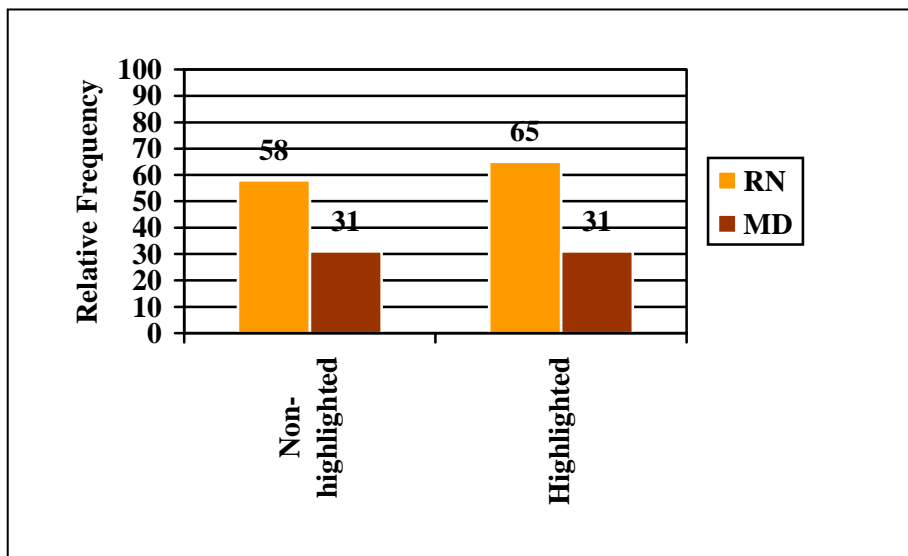


Overall the nurses generated more recalls (70% and 76%) in their summaries from both the highlighted and non-highlighted cases than the physicians (40% and 41%).

These differences were statistically significant ($p < 0.001$). The physicians, however, generated more inferences ($p < 0.001$), more interventions ($p < 0.001$) and more conditional statements ($p = .002$) than the nurses generated in their summaries. A pairwise comparison between the physicians and nurses in their generation of propositional types showed similar statistically significant results in regard to the relative frequencies of these propositional types.

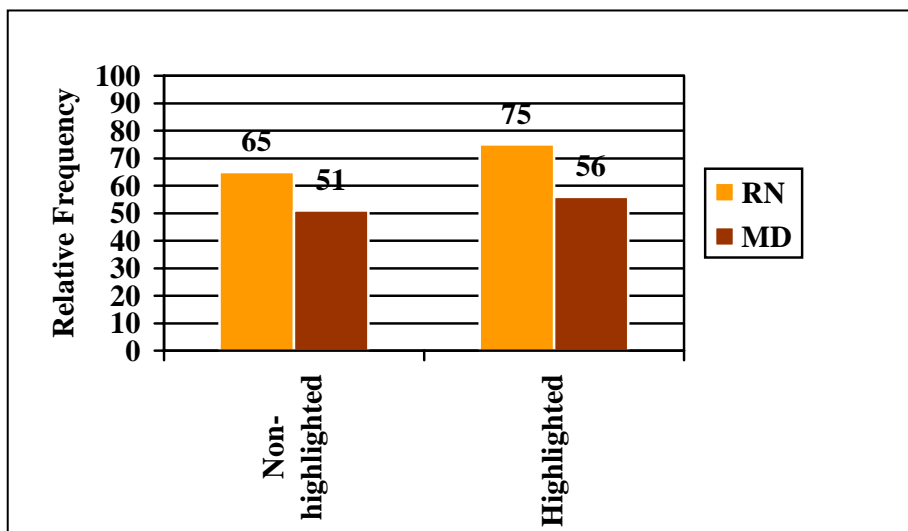
Thus far, differences were noted between clinician types for number of propositions and types of propositions within the same case display. Another difference was noted in the amount of highlighted versus non-highlighted information the physicians and nurses included in their summaries. The highlighted information that the physicians and nurses included in their summaries from the highlighted cases was compared to the proportion of hypothetically highlighted information from the non-highlighted cases. Meaning that in the analysis of their summaries from the non-highlighted cases, it was determined which of that information was highlighted in the original highlighted case. This comparison was made to determine if the highlighting and content affected the inclusion of information or just content affected the inclusion of information. Overall the nurses included a larger proportion of highlighted information in their summaries than the physicians included in their summaries. Figure 11 shows these differences between the physicians and nurses.

Figure 11. MD & RN inclusion of highlighted information



The relative frequencies showed that the nurses included nearly twice (58% - 65%) the proportion of highlighted information than the physicians (31%) included in their summaries. These differences were statistically significant ($p < .001$). However, it was considered that there might be confounding factors in these results since the physicians overall generated more propositions such as interventions, conditional statements, and inferences that would not necessarily be directly derived from the cases, thus increasing the proportion of highlighted information for the nurses and decreasing the proportion of highlighted information for the physicians. So recalled information, which is directly derived from the cases and could be classified as highlighted or non-highlighted was examined and compared between clinician types. Figure 12 shows the differences between the relative frequency of highlighted recalled information directly from the highlighted case and hypothetically from the non-highlighted case.

Figure 12. MD & RN inclusion of highlighted recalled information



Upon examination of only the differences in the relative frequency of highlighted recalled information between the physicians and nurses, the nurses still provided proportionally more highlighted information in their summaries than the physicians generated in their summaries. The differences were statistically significant in the non-highlighted and highlighted cases between the physicians and nurses ($p < 0.001$). It is hypothesized that the nurses were more affected by the highlighted information in the cases than the physicians; however, the nurse experts were also considered to be influential in determining the important information to nurses.

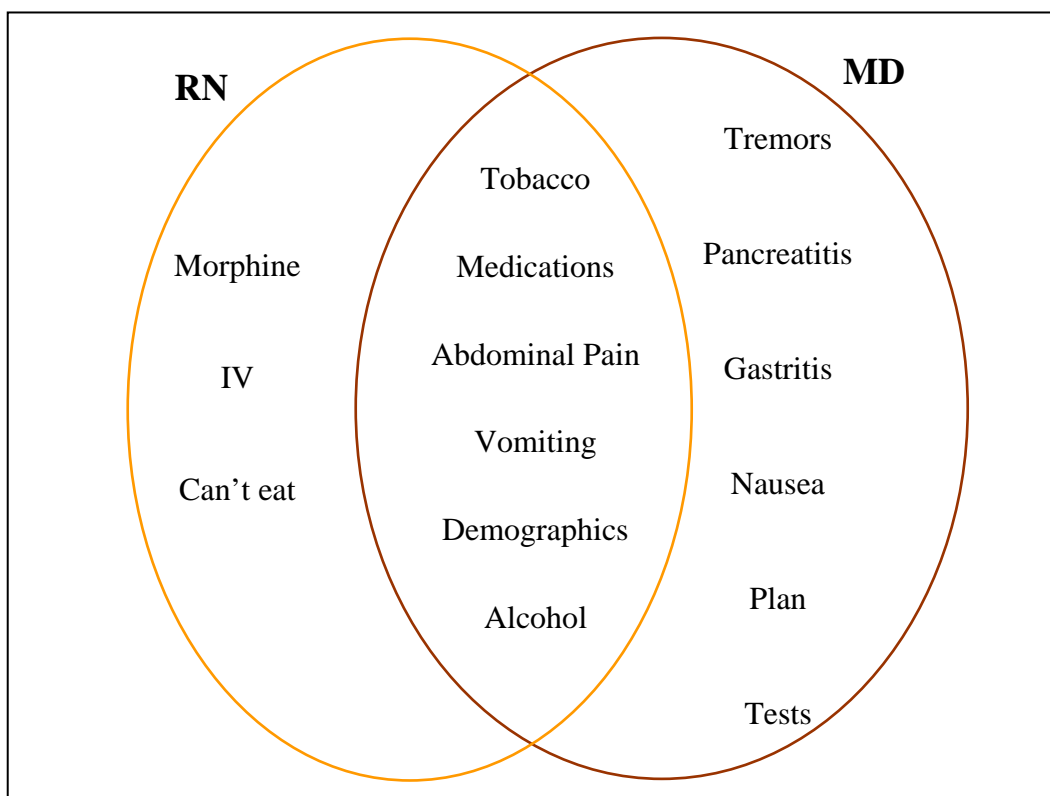
The main effect in this study (Appendix O) between the clinician types was shown to be the occupation of the subjects as being most influential in determining what information was included in their summaries. There was no significant interaction effect noted between the different displays of information (highlighting) and occupation.

Conceptual Differences between the Physicians and Nurses

There was a very large variance in the number of concepts presented by the physicians and by the nurses in their summaries of the cases. These data are presented by case content and case display to show conceptual differences between the physicians and nurses. In the pancreatitis non-highlighted case, physicians provided a total of 540 concepts with 155 different concepts versus the nurses who provided a total of 247 concepts with a total of 54 different concepts. In the pancreatitis highlighted case, the physicians provided a total of 498 concepts with 134 different concepts versus the nurses who provided a total of 277 concepts with 75 different concepts. As in accordance with the larger number of propositions, the physicians provided more concepts than the nurses. However, it must not be assumed that the number of different concepts was equally distributed throughout the physician and nurse summaries. Actually, very few of the different concepts were included by $\geq 50\%$ of the physicians and nurses. For example, in only 12/155 (7.7%) different concepts in the pancreatitis non-highlighted case and in only 12/134 (8.9%) different concepts in the pancreatitis highlighted case were included by $\geq 50\%$ of the physicians. The remainder of the different concepts was mentioned by less than 50% of the physicians. The same was true for the nurses. In pancreatitis non-highlighted case, only 9/54 (16.6%) different concepts were included by $\geq 50\%$ of the nurses and in the pancreatitis highlighted case, only 10/54 (18.5%) different concepts were included by $\geq 50\%$ of the nurses. To review the agreement by the majority of the clinician types, only concepts that were mentioned by $\geq 50\%$ of either the physicians or nurses are presented for comparison. These conceptual agreements are shown in Appendix N which shows the number of subjects that included the concept in their

summaries as well as the total number of times the concept was included in the summaries of both the pancreatitis non-highlighted and pancreatitis highlighted cases. Figure 13 shows a direct comparison with a conceptual graph of the concepts mentioned by $\geq 50\%$ of the physicians and nurses in their summaries of the pancreatitis non-highlighted case.

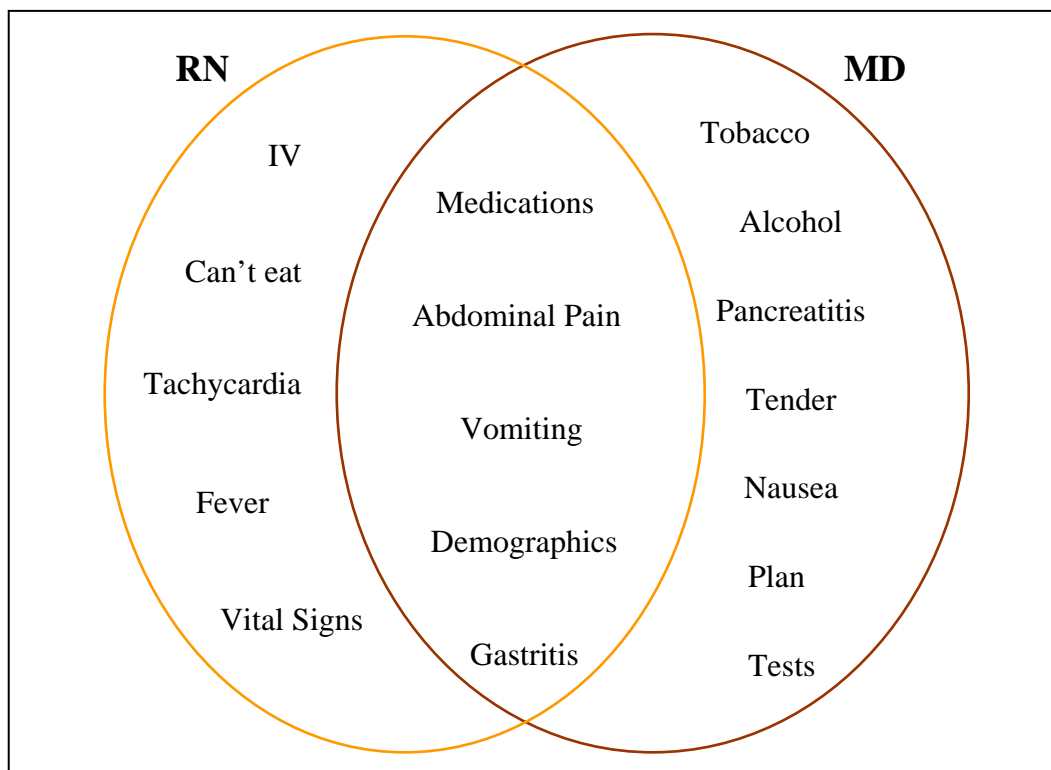
Figure 13. MD & RN conceptual graph of pancreatitis non-highlighted case



As shown in Figure 13, only 6 concepts were consistently included in both cases by $\geq 50\%$ of both the physicians and nurses: tobacco, medications, abdominal pain, vomiting, demographics, and alcohol consumption. However, an examination of the concepts only included by the nurses or only included by the physicians showed concepts that were important to the practice pattern of the respective clinician. For example, the nurses are concerned with functional issues such as IV's, diet, and pain control. The physicians, however, focus on diagnosis, treatment and management as shown by their concepts of

pancreatitis, plan, and tests. The same types of concepts were generated in the summaries of the pancreatitis highlighted case. Figure 14 shows the conceptual graph of this case.

Figure 14. MD & RN conceptual graph of pancreatitis highlighted case



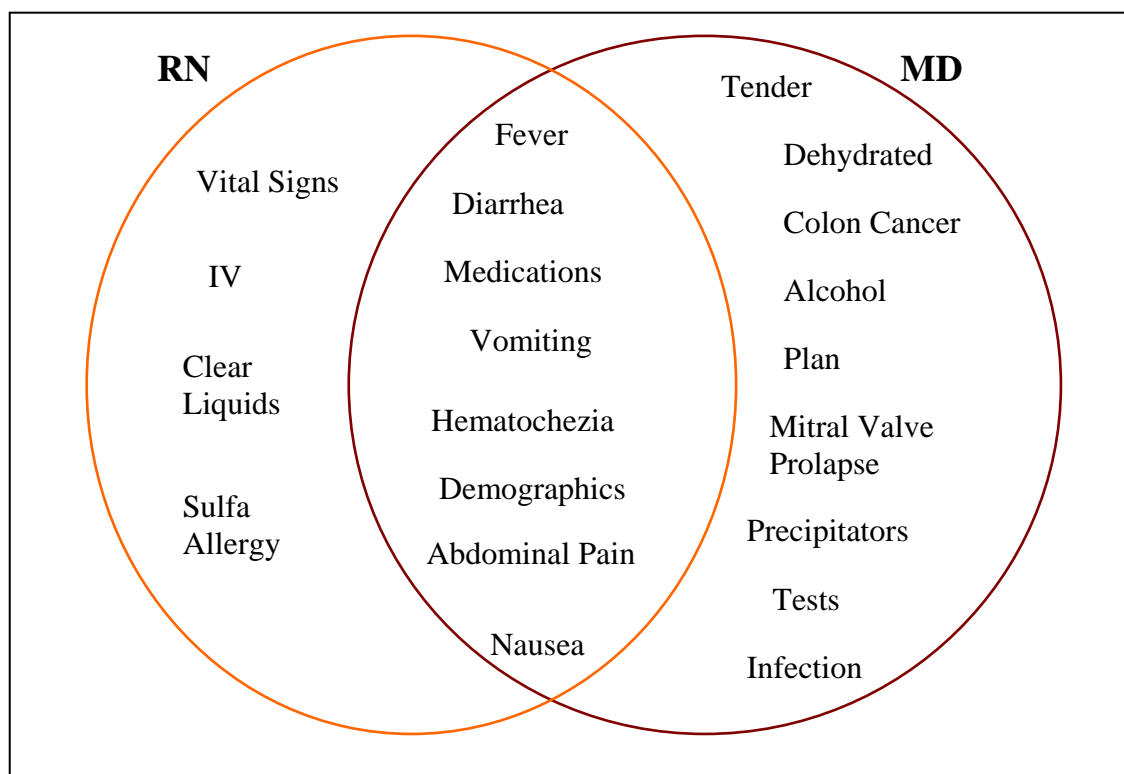
In the pancreatitis highlighted case, $\geq 50\%$ of the physicians and nurses agreed upon 5 concepts. These were medications, abdominal pain, vomiting, demographics, and gastritis. However, the concepts that each clinician type were in agreement on within and in disagreement on between clinician type were similar to the non-highlighted case in regard to the practice model of the nurses and physicians respectively. For example, the physician's practice model focuses on the diagnosis which as stated earlier was included by $> 50\%$ of the physicians, however, this was not found in the nursing summaries. So,

the concepts included by the physicians and nurses in their summaries from the pancreatitis cases could be attributed to their respective practice models.

There was also a very large variance in the number of concepts presented by the physicians and by the nurses in their summaries of the gastroenteritis cases. In the gastroenteritis case non-highlighted, the physicians provided a total of 461 concepts with 103 different concepts versus the nurses who provided a total of 250 concepts with a total of 57 different concepts. In the gastroenteritis highlighted case, the physicians provided a total of 546 concepts in their summaries with 152 different concepts. The nurses provided a total of 250 concepts in their summaries with 59 different concepts. As in the pancreatitis cases, the number of different concepts was not equally distributed throughout the physician and nurse summaries. Actually, very few of the different concepts were included by $\geq 50\%$ of the physicians and nurses. In the gastroenteritis non-highlighted case, only 17/103 (16.5%) different concepts and in the highlighted case only 16/152 (10.5%) different concepts were included by $\geq 50\%$ of the physicians. The remainder of the different concepts was mentioned by less than 50% of the physicians. The same was true for the nurses. In gastroenteritis non-highlighted case, only 12/57 (21.0%) different concepts were included by $\geq 50\%$ of the nurses and in the highlighted case, only 10/59 (16.9%) different concepts were included by $\geq 50\%$ of the nurses. As for the nurses, the remainder of the different concepts was mentioned by less than 50% of the nurses. To review the agreement between the clinician types, only concepts that were mentioned by $\geq 50\%$ of the subjects are presented for comparison. These conceptual agreements are shown Appendix P which shows the number of subjects that included the concept in their summaries as well as the total number of times the concept was included

in the summaries in both the non-highlighted gastroenteritis case and highlighted gastroenteritis case. The differences in the clinician summaries are separated by a conceptual graph in both of the non-highlighted and highlighted cases. These conceptual graphs are depicted in Figures 15 and 16.

Figure 15. MD & RN conceptual graph of gastroenteritis non-highlighted case



Only 8 concepts were consistently included by $\geq 50\%$ of both nurses and doctors in the non-highlighted case; diarrhea, fever, medications, nausea, vomiting, demographic, abdominal pain, and hematochezia. There were more unshared concepts than there were shared concepts between the clinician groups, however, the shared concepts provided an overall fundamental picture of the patient case and unshared concepts were reflective of the clinician's specific practice model.

Figure 16. MD & RN conceptual graph of gastroenteritis highlighted case

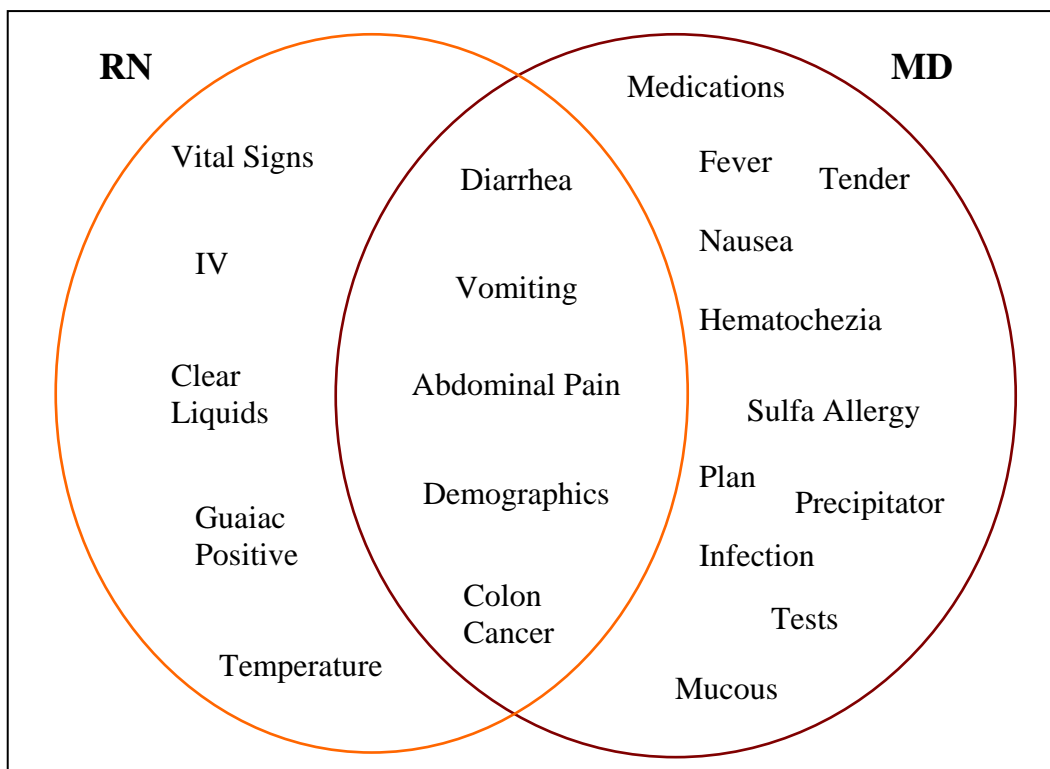


Figure 16 shows the differences between the clinician types in the gastroenteritis highlighted case. In the gastroenteritis highlighted case, $\geq 50\%$ of the physicians and nurses agreed upon 5 concepts; diarrhea, colon cancer, vomiting, demographics, and abdominal pain. Again, there were more unshared concepts between the clinicians than shared concepts. The shared concepts provided a basic picture of the patient, the unshared concepts were reflective of the clinicians' practice model, however, in the physician cases, there were simply more concepts generated than the nurses generated in their summaries.

Differences within Clinicians with Different Information Displays

It was also hypothesized that different displays of the same information will lead to different mental models for the same clinician. The analysis of the summaries

revealed some significant differences within the physician groups and nurse groups, respectively. Using occupation as the only independent variable, differences were examined between the different displays of the same information within the respective groups of clinicians. The same independent variables as the first hypothesis were examined; time to complete each case, the number of propositions, types of propositions, and conceptual differences.

A Review of the Nurse Summaries

Upon comparing the nursing summaries between the non-highlighted and highlighted cases, there were no significant differences between the time to complete the cases, the number of propositions or the relative frequency of the highlighted propositions included in the nursing summaries. A total of 24 nurses were randomized to a non-highlighted and highlighted case for a total of 48 cases reviewed by the nurses.

The nurses took approximately the same mean amount of time to review both the non-highlighted and highlighted cases 6.87 ± 3.13 and 7.08 ± 3.02 minutes, respectively. There was also very little difference between the mean number of propositions the nurses generated in their summaries from both the non-highlighted and highlighted cases. They generated a mean number of 21.50 propositions from the non-highlighted cases and 22.83 propositions from the highlighted cases. Although the nurses included on the average slightly more highlighted information in their summaries from the highlighted cases than from the non-highlighted cases (65% versus 58%), these differences were not statistically significant.

Finally, the relative frequency and types of propositions the nurses generated in their summaries were reviewed. No statistical differences were found within the nursing

group. In essence, this group was fairly consistent in the type and amount of information they included in their summaries.

Conceptual Differences Between the Nursing Summaries

A comparison of the number of concepts that the nurses included in their summaries showed that they included 247 concepts in the pancreatitis case non-highlighted and 277 concepts in the pancreatitis highlighted case. Of the 54 different concepts included in pancreatitis non-highlighted, only 9 (17%) were included by $\geq 50\%$ of the nurses. In the pancreatitis highlighted case, of the 75 different concepts they included in their summaries, only 10 (13%) were included by $\geq 50\%$ of the nurses. A comparison of the agreement in concepts between the cases was made and showed that only 6 concepts were in agreement by $\geq 50\%$ of the all nurses. These concepts are shown in a table format in Appendix Q and in a graphical format in Figure 17.

Figure 17. RN conceptual graph of pancreatitis non-highlighted and highlighted cases

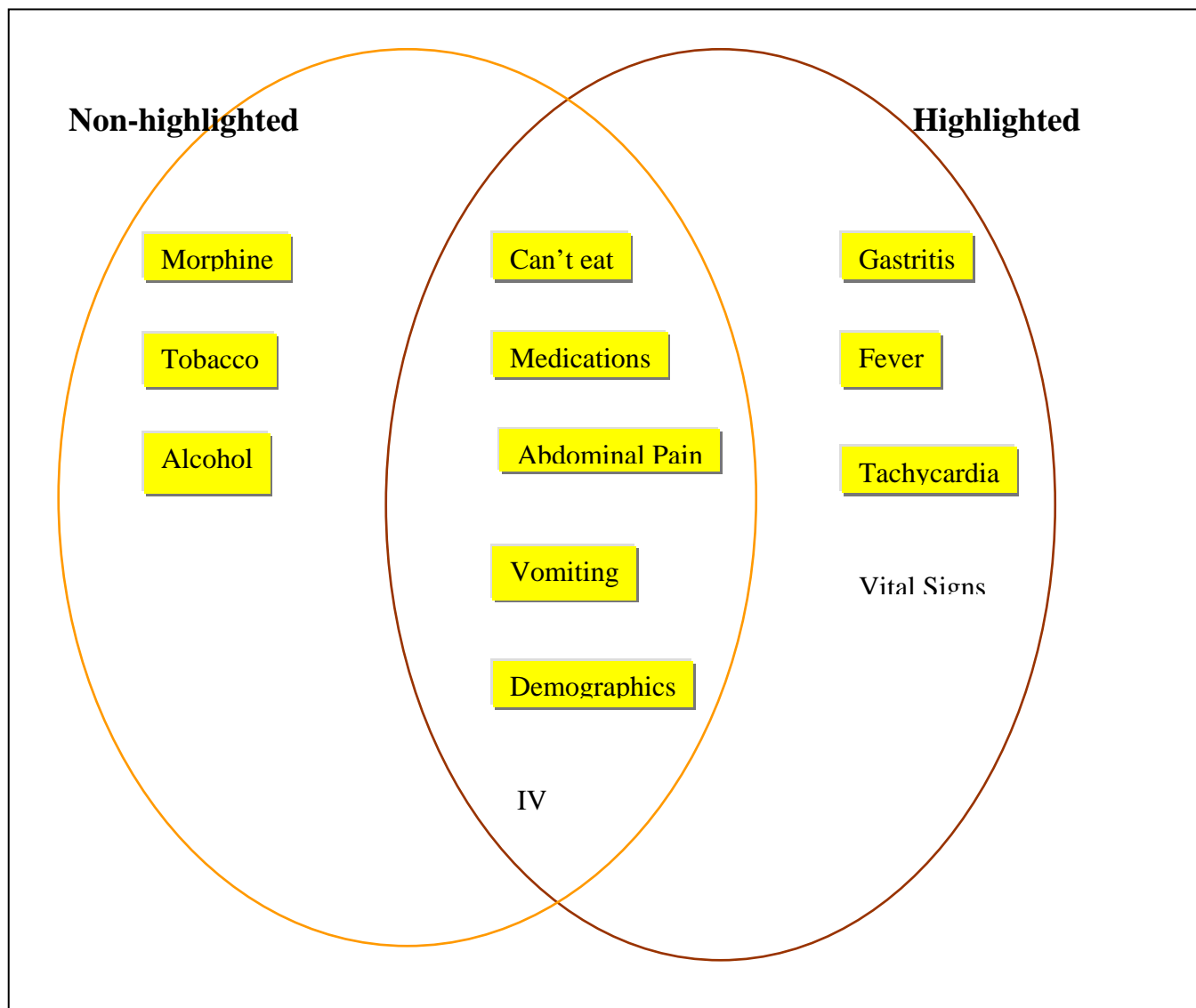
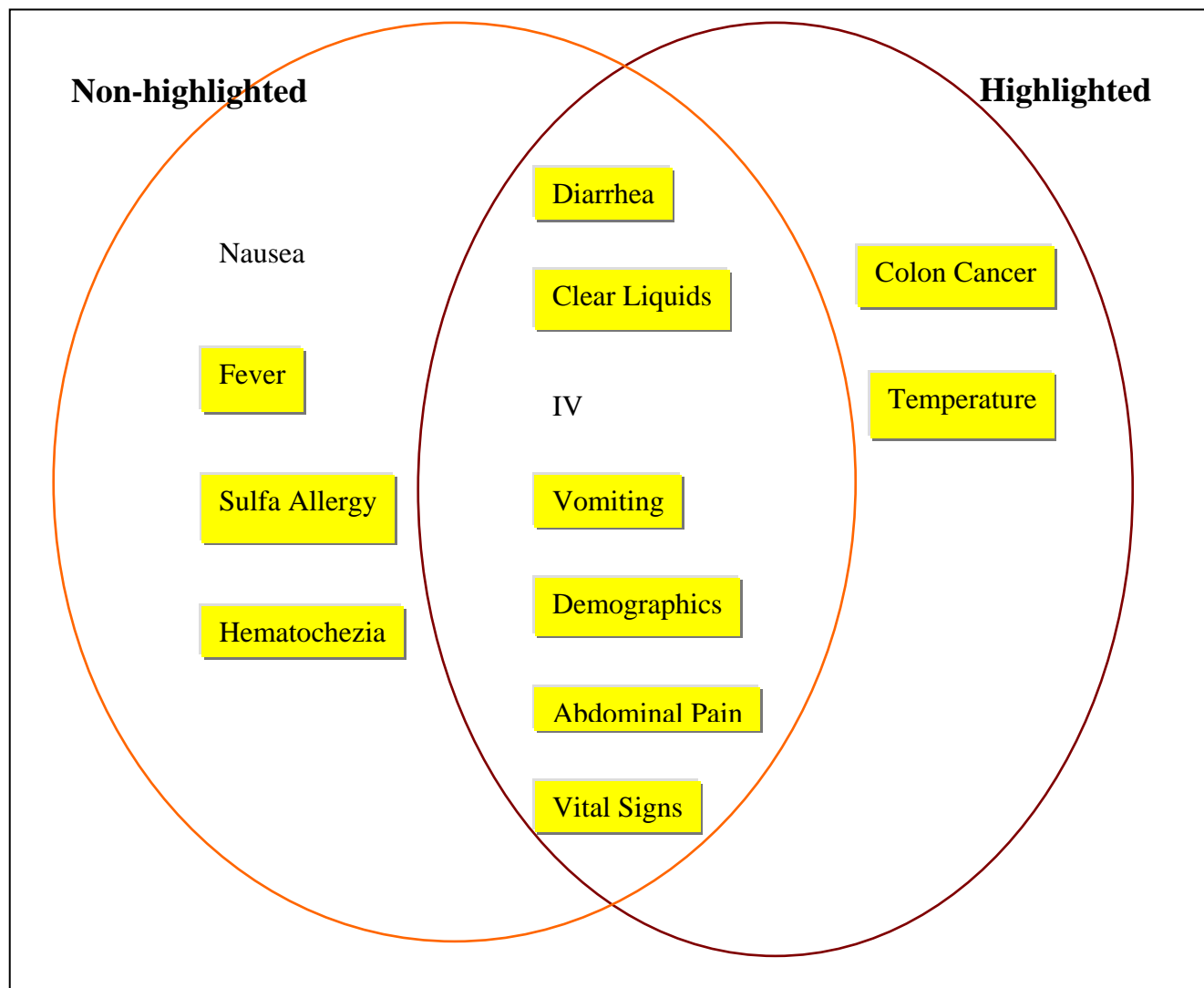


Figure 17 shows that there are more agreed upon concepts within the nursing summaries between the same case content and different case displays. Overall the nurses agreed upon 6 different concepts and disagreed upon three concepts in the non-highlighted case and 4 concepts in the highlighted case. There was no significant difference between the amount of concepts included in the nursing summaries that were highlighted in the original case versus non-highlighted in the original case. The

highlighted concepts in the original case are highlighted yellow in the conceptual graph, which shows that the majority of concepts are highlighted concepts. It appears that content is more important than highlighting. Additionally, the nurse experts may have also consistently highlighted the information that is important to the nurses.

In gastroenteritis non-highlighted and highlighted cases, the nurses included exactly the same number of concepts in each case respectively, 250 concepts. There was additionally variance in these cases as well, with the number of different concepts. In gastroenteritis non-highlighted case, there were 57 different concepts and in gastroenteritis highlighted case, there were 59 different concepts. Of a total of 15 concepts that were included by $\geq 50\%$ of the nurses in either case, 11 were in agreement in the gastroenteritis non-highlighted cases and 9 concepts were in agreement in the gastroenteritis highlighted case. However, in comparing agreement between the cases, only 7 concepts were in agreement by $\geq 50\%$ of the nurses. These concepts are shown in a table format in Appendix R and in a graphical format in Figure 18.

Figure 18. RN conceptual graph of gastroenteritis non-highlighted and highlighted cases



The concepts in agreement between the same content cases but different displays are diarrhea, clear liquids, IV, vomiting, demographics, abdominal pain, and vital signs. There were four concepts included in the non-highlighted case summaries and there were two concepts in the highlighted nurse case summaries that were included by $\geq 50\%$ of the nurses.

Once again there was no significant difference between the amount of concepts included in the nursing summaries that were highlighted in the original case versus non-

highlighted in the original case. The highlighted concepts in the original case are highlighted yellow in the conceptual graph, which shows that the majority of concepts are highlighted concepts. It appears that content is more important than highlighting.

Overall, there were more concepts in agreement between the highlighted and non-highlighted cases than in disagreement in the nursing summaries. Although on the whole, there were a large number of different concepts included by the nursing group, only 13% – 26% of all of the concepts generated by all of the nurses in their summaries were included by > 50% of the nurses. The inclusion of highlighted information (see conceptual graph) showed that content appears to be more important than display since the majority of the concepts included by >50% of the nurses are highlighted concepts regardless of display type. However, upon including all propositions included by all of the nurses, the nurses included more highlighted propositions from the highlighted case in their summaries than from the non-highlighted cases in their summaries. Although it appears that highlighting has influenced the nurses in their inclusion of more highlighted information, but statistically, the interaction between highlighting and clinician type, only approached significance.

A Review of the Physician Summaries

Upon comparing the physician summaries between the non-highlighted and highlighted cases, there were no significant differences between the time to complete the cases, the number of propositions or the relative frequency of the highlighted propositions included in the nursing summaries. A total of 24 physicians were randomized to a non-highlighted and highlighted case.

The physicians took approximately the same mean amount of time to review both the non-highlighted and highlighted cases 9.6 ± 4.17 and 9.5 ± 3.95 minutes, respectively. There was also very little difference between the mean number of propositions the physicians generated in their summaries from both the non-highlighted and highlighted cases. They generated a mean number of 42.54 ± 25.74 propositions from the non-highlighted case and 44.50 ± 27.48 propositions from the highlighted case. As noted in the large standard deviations, the variance in the range of propositions within each of these cases was quite large. The range of propositions was 14-69 in the non-highlighted case, versus the highlighted case, the range was 18-121. Finally, the amount of highlighted information the physicians included in their summaries did not differ between the highlighted and non-highlighted cases. In the physician's summaries from the non-highlighted and highlighted cases, 31% of the information they included in their summaries was highlighted information.

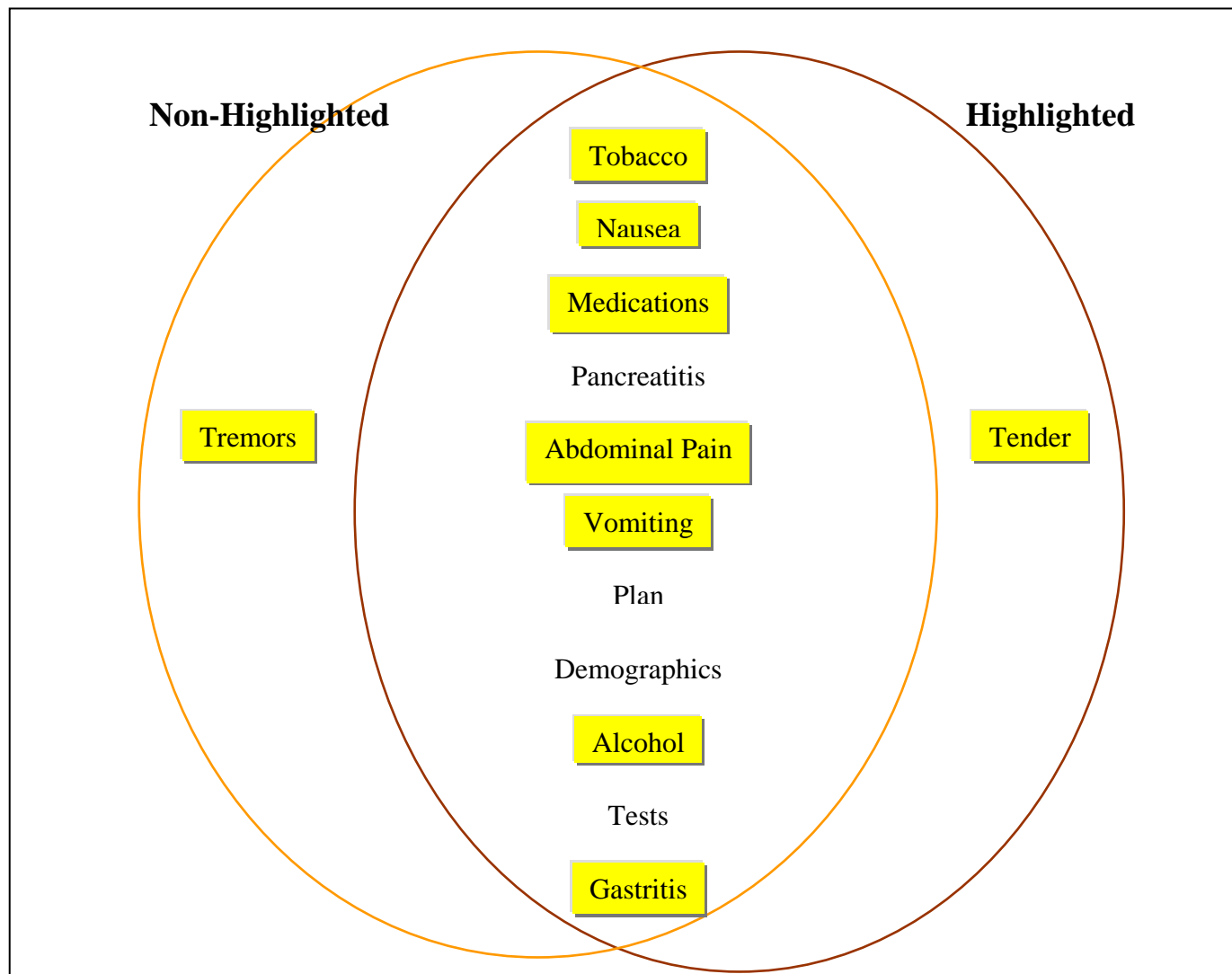
Finally, the relative frequency and types of propositions the physicians generated in their summaries was reviewed. No statistical differences were found within the physician group, which, means that this group was fairly consistent in the type of information they included in their summaries.

Conceptual Differences between the Physicians

Comparing the number of concepts that the physicians included in their summaries showed only a minor difference between the pancreatitis non-highlighted and pancreatitis highlighted case. The physicians included 540 concepts in the pancreatitis non-highlighted case and 498 concepts in the pancreatitis highlighted case. Of the 155 different concepts included in non-highlighted case, only 12 were included by $\geq 50\%$ of

the physicians. Of the 134 different concepts they included in their summaries from the highlighted pancreatitis case, only 12 were included by $\geq 50\%$ of the physicians. A comparison of the agreement in concepts between the cases was made and showed that of the 13 different concepts included by $\geq 50\%$ of the physicians in either case, 11/13 were in agreement by $\geq 50\%$ of the physicians. These concepts are shown in Appendix S in a table format and in Figure 19. These are abdominal pain, demographics, alcohol, gastritis, medications, nausea, pancreatitis, plan, tests, tobacco, and vomiting. In the pancreatitis non-highlighted case, there was one other concept that was included by $\geq 50\%$ of the physicians, tremors. In the pancreatitis highlighted case, there was additionally only one other concept that were included by $\geq 50\%$ of the physicians, tender. Highlighting again did not seem to make a difference in the concepts included in the physician summaries since there was largely agreement by $\geq 50\%$ of the physicians regardless of highlighting.

Figure 19. MD conceptual graph of pancreatitis non-highlighted and highlighted cases

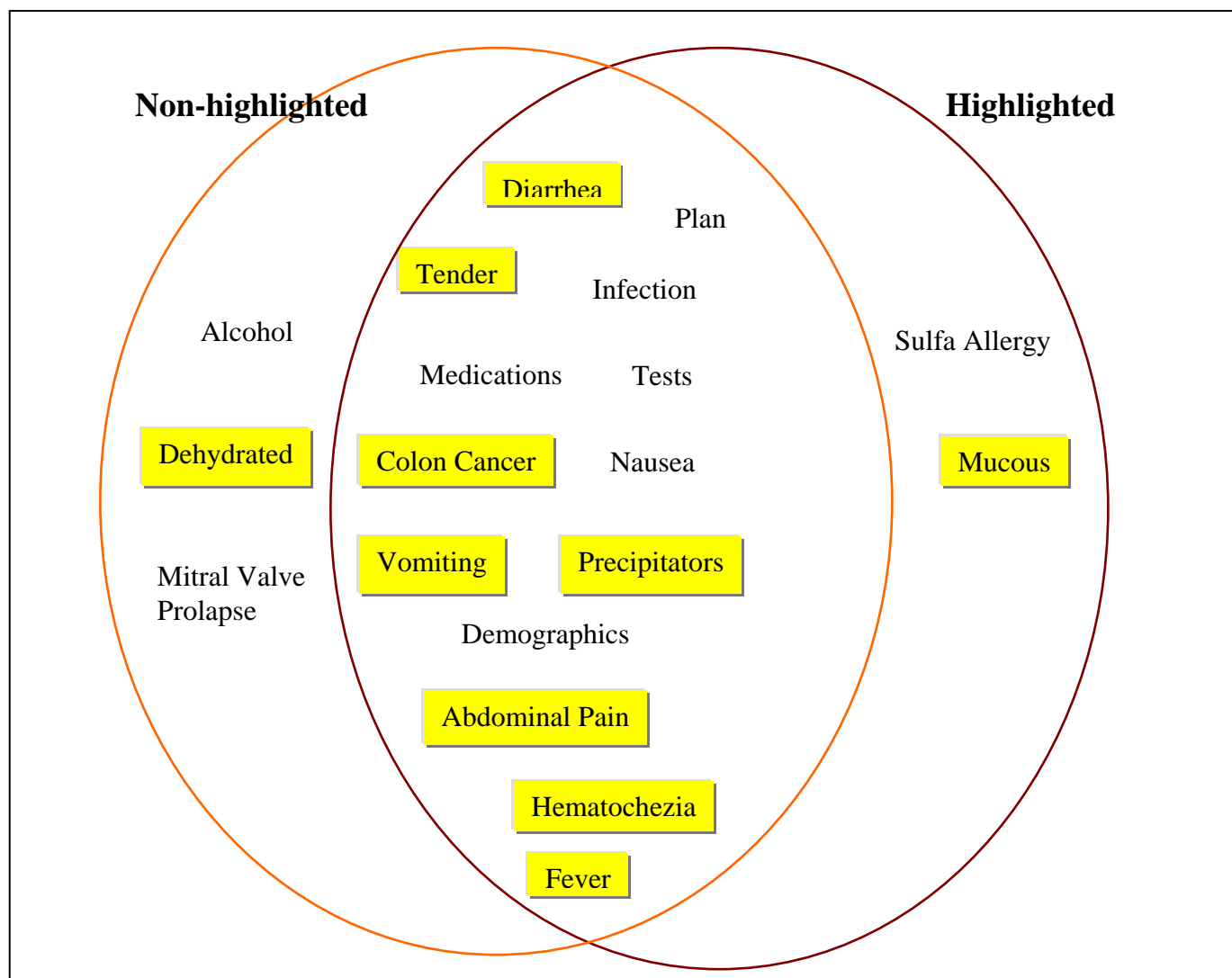


Interestingly 19/24 (79.1%) of the physicians included pancreatitis as a differential in their review of this case, whereas only 1/24 nurses indicated that this could be potentially a case of pancreatitis. The remaining physicians indicated that this was a potential case of gastritis, peptic ulcer, and/or acute abdomen. The remaining nurses only reiterated what was noted in the mock medical record as the assessment of the patient, which was abdominal pain. In the pancreatitis cases, although there was a large variance among all of the concepts included by all of the clinicians, there was largely agreement in

the case content included by $\geq 50\%$ of the clinicians. Essentially, their comprehension of the pancreatitis cases was fairly consistent.

In the gastroenteritis non-highlighted case the physicians included a total of 461 concepts in their summaries, which included 103 different concepts. In the gastroenteritis highlighted case the physicians included in their summaries a total of 546 concepts, which included 152 different concepts. However, there were only a total of 19 concepts included by $\geq 50\%$ of the physicians in their summaries. Of these 19 concepts, 17 were in agreement in their summaries from the gastroenteritis non-highlighted case and 16 were in agreement in their summaries from the gastroenteritis highlighted case. However, in comparing agreement between the non-highlighted and highlighted cases, only 14 concepts were in agreement by $\geq 50\%$ of the physicians. These concepts are shown in Appendix T and in Figure 20. These are abdominal pain, colon cancer, demographics, diarrhea, fever, hematochezia, infection, medications, nausea, plan, precipitators, tender, tests, and vomiting. There additionally were 4 different concepts in the non-highlighted gastroenteritis case that were not in agreement between the different display cases, but were included by $\geq 50\%$ of the physicians for that case; dehydrated, alcohol, allergy, and mitral valve prolapse. In the gastroenteritis highlighted case, there were a total of 2 concepts that were not in agreement between the different display cases, but were included by 50% of the physicians; allergy and mucous.

Figure 20. MD conceptual graph of gastroenteritis non-highlighted and highlighted cases



In the gastroenteritis cases, 19/24 of the physicians (79.1%) indicated that this was a case of gastroenteritis or some type of infectious process. The remaining 5 physicians included in their differential the diagnoses of perforation, ulcerative disease, gallstones, food poisoning, and/or obstruction. Once again, the nurses only included the information that was in the assessment section of the mock medical record, which was diarrhea and vomiting.

Overall, the physician's comprehension of the gastroenteritis case was fairly consistent within this group. Although there was a large amount of variance within the summaries as a whole, the conceptual agreement by $\geq 50\%$ of the physicians between the case displays were largely stable.

Overall, the inclusion of highlighted information (see conceptual graphs) showed that content appears to be more important than display since the majority of the concepts included by $>50\%$ of the physicians are highlighted concepts regardless of display type. However, upon including all propositions included by all of the physicians, the physicians included the same proportion of highlighted propositions from the highlighted case and from the non-highlighted cases in their summaries. Statistically, highlighting did not influence the physicians in their inclusion of highlighted information.

Subject Comments

During the course of the experiment many subjects offered unsolicited comments on the display of the experimental interfaces. These comments are presented here. Many of the physicians found the talk-aloud procedure distracting and interrupted their thought processes. They stated that reading and thinking aloud was very different from how they were used to reading and summarizing patient information. Additionally the physicians and nurses commented that summarizing a case from memory was difficult and that they usually worked from notes. Finally, all of the physicians found the highlighting distracting and thought that reviewing the highlighted cases took longer because they were fearful that they would miss important un-highlighted information. The nurses, however, commented that they found the highlighted information helpful and thought that it made reviewing the cases easier.

SUMMARY OF THE STUDY

In this dissertation I have laid a theoretical background and methodological framework to understand how the clinician's background, their tasks, and the display of information interact to affect the comprehension and thus mental models constructed by clinicians. The theoretical ideas are borrowed from the psychology, cognitive science, computer science, medicine, and nursing literature. The methodological framework of verbal protocols and propositional analysis are borrowed from the psychology, cognitive science and medical informatics literature and are considered robust evaluation tools of text comprehension (V.L. Patel, Arocha, Diermeier et al., 2001). The purpose of this chapter is to present a discussion of the findings, present the limitations, address the implications for health informatics and provide a summary of the study.

Previous studies that have used a method of natural language representation, propositional analysis, to understand clinician comprehension of patient cases, have used the coding scheme of only recalls, inferences, and un-coded as means of understanding the cognitive processes of clinicians (C. Johnson et al., 2002; T. R. Johnson et al., 2001; V.L. Patel et al., 1994; V.L. Patel et al., 1986). However, an iterative review of these clinician's summaries revealed that including only recalls, inferences, and errors would have excluded a large amount of information. Therefore, this study included a more complete coding scheme not previously used to categorize medical summaries generated by physicians and nurses. Adding categorizations such as assumptions, negatives, interventions, and conditional statements allowed a more accurate and complete picture of particularly the physician summaries. Although overall, 73% of the propositions in the nurse summaries were recalls, 16% were inferences, and 11% comprised the other types

of propositions, only 40% of the propositions in the physician summaries were recalls, 29% were inferences, and the remaining 31% comprised the other types of propositions. Coding these other types as un-coded would have left out 31% of information in the physician summaries and 11% in the nurse summaries. Adding these additional categorizations enhanced the understanding of how clinicians comprehend patient information.

Through these coding schemes, I was able to broadly appreciate the differences between how clinicians comprehend a patient problem. Whereas the nursing representations of the patient problem was somewhat more external as evidenced through their large percentage of recalls, the physician representations of the patient problem were more multifaceted and causal in nature as evidenced by their inclusion of a larger percentage of inferences and conditional statements than the nurses. This reflects the differences in their practice models, whereby physicians are trained to diagnose and treat patients, and nurses are trained to diagnose functional problems and monitor changes in physiological status (Simpson, 1998a). The differences both between different clinician types and within clinician types are important to understand because how a clinician understands a patient can affect communication and coordination of care. Although it is known that the roles of each are different due to their respective practice models, the implications of these differences have not been previously studied.

Comparison of Mental Models

In general there were some differences and similarities in the mental models constructed both within and between physicians and nurses after their review of the cases. The differences were reflected in the number of propositions, the type of propositions,

and the concepts they included in their summaries. Some of the differences found were considered a direct influence of the clinician's background and tasks. Some of the other differences were thought a direct influence of the display of information and some were considered an interaction of the clinician's background, their tasks, and the influence of the display of information.

The formation of the physician and nurses mental models of the experimental cases showed that on the average the physicians took more time (9.56 minutes) and included more propositions (43.24 propositions) per summary of each case they reviewed in comparison to the nurses who took on the average 6.97 minutes to review each case and included on the average 22.16 propositions per case. The time difference is thought to be a reflection of the amount of information the subjects included in their summaries as shown in their number of propositions.

The specific information that each clinician type reviewed is thought to be influenced by their background and tasks. On the one hand, since the physician's tasks focus on diagnosing, treating, and managing medical problems, it was not surprising to find that on the average this group reviewed 14.29 out of the 15 sections. They specifically have a need to know as much information as possible since they are ultimately making the decisions regarding diagnosis, management, and treatment. However, considering their tasks, it was surprising to note that 25% of the physicians did not review the assessment section, 12.5% did not review the allergy and physician orders sections and nearly 7% did not review the all of the physical exam sections. However, 100% of the physicians did review the history of present illness, nursing notes, cardiovascular, respiratory and gastrointestinal physical exam, and vital signs section. It

is unknown why they did not review particular sections, and although I could make some assumptions, such as they didn't consider these sections important or they were in a hurry, or they just simply overlooked the sections, it was not within the scope of this research to study why clinicians excluded sections from their review of the cases.

The nurse's tasks on the other hand, center on identifying high-risk individuals, diagnosing functional problems, and monitoring and reporting changes in physiological status. It was interesting to note that they included on the average fewer sections in their review of the mock medical record (12.6 sections) than the physicians included in their review ($p = .002$). It was surprising to find that 33% did not review the allergy section, 25% did not review the intake and output section, 12% did not review the physician's orders and vital sign sections, and 8% did not review the nursing notes. These sections contain information that directly impacts their care of the patient. For example, since the nurses primarily are the administrators of the medications knowing the patient's allergies is one of their responsibilities. Monitoring the patient's functional status includes knowing the intake and output of the patient as well as vital sign information. Carrying out the orders of the physicians is yet another primary responsibility of the nurses. Why they did not review this information may be attributed to the artificial setting of the experiment and perhaps a desire to review only a minimal number of sections. However, again, these reasons are purely speculative and it was not within the scope of this research to study why they excluded sections from their review of the cases.

Same Information Display

My hypothesis that the same display of information leads to different mental models among physicians and nurses was verified in this study. Upon comparison of the

structure of the summaries between the physicians and nurses, there were some significant differences between these two groups in the same displays of information. Consistently in all four cases, the nursing summaries proportionately contained more recalls and more highlighted information than the physician summaries. The physician summaries proportionately contained more propositions, inferences, interventions, and conditional propositions than the nursing summaries. There were not statistical differences in the proportion of assumptions or negative propositions between the physicians and nurses.

These results suggest that the physicians represented this information at a more abstract level, while the nurses recalled more descriptive information. Studies have shown that experts make more inferences and novices employ more direct recall (V.L. Patel & Groen, 1986). While this study compared expert to novice physicians, the differences noted between the physicians and nurses in my study can be explained not through the expert/novice paradigm, but through the differences in their practice models. Since the physician's practice model and tasks include more problem solving and diagnosing than the nurses, these results are not particularly surprising. Research has shown that during the process of problem-solving, individuals develop internal representations and links between these representations, whereby inferences are drawn (Chi et al., 1981; Hassebrock et al., 1993). The conditional statements made only by the physician group are also another example of linking information to form hypotheses. Yet, since the nursing practice model centers partially on observing and reporting changes, it is not surprising that they included more recalled information than the physicians. The physician's inclusion of more interventions than the nurses is also

reflective of their practice model that includes an overall management plan for the patient.

The type and amount of information each clinician included from the various sections in their summaries is also reflective of their particular practice models. The nursing summaries contained more information from the nursing notes, physician orders, demographic, and intake and output sections, whereas the physician summaries contained more information from the assessment, review of systems, and physical exam sections. It is expected that the nurses would draw a significant amount of their information from the nursing notes. Since their care of the patient partially depends on carrying out the physician orders and observing and recording functional changes, none of these results were unexpected. Also, there were expected differences between the physician summaries and the nurse summaries. Since the physician's practice model focuses on problem solving, diagnosing, and management, it was not surprising that their summaries contained more information from the assessment, review of systems, and gastrointestinal sections. Although these particular data show the major differences between the physicians and nurses in terms of where they drew some of their summary information from the mock medical record, it does not show the particular conceptual differences.

There was a large variance in the number of concepts included by the physicians and nurses in their summaries. The variance was not only between these groups, but also within these groups. Although the formation of mental models depends upon prior knowledge, it is apparent that the shared information is minor compared to the diversity within and between the groups. The within group diversity is discussed in the next section. This section mainly focuses on the differences between the shared and unshared

concepts within the mental models formed by the physicians and nurses given the same display of information.

In the non-highlighted versus the highlighted cases, there was a difference in terms of the percentage of concepts in agreement between the physicians and nurses, but there was consistency as well in terms of this percentage. For example, in the non-highlighted cases, the physicians and nurses were in agreement on 40% of the concepts whereas in the highlighted cases, they were in agreement on 29% and 23% of the concepts. Although the same displays of information showed some agreement in their mental models, overall there was more disagreement. The agreement occurred in the demographic, presenting complaint, habits, one minor piece of medical history, and medication information. The disagreement was more of a reflection of their different practice models, rather than a factor in the display of information. For example in the nursing summaries, the concepts included by only the nurses were related to the patient's functional status, IV, and changes in physiological status. In the physician summaries, however, the concepts included by only the physicians included present signs and symptoms, historical information, precipitators of the event, and diagnostic information. Since the role of the nurse is to monitor changes in physiological status, focus on preventative strategies, diagnose and monitor functional responses, and carry out the treatment plan as ordered by the physician and the role of the physician is to diagnose, treat, and manage patient problems (Schoop & Wastell, 1999; Simpson, 1998a), the differences in their mental models of the patient are not surprising. The question then becomes, is the physician's and nurses agreed upon understanding of the patient enough to promote communication and collaboration of care or can the information, which is

different pose problems in terms of communication and collaboration of care.

Interestingly, their respective mutual understanding of the patient is merely a skeleton of the complexity of the patient's problems. An argument can be made that the differences between what each respective profession believes to be important information could lead to problems with communication and collaboration of care. First, if the physicians and nurses are not in agreement regarding their understanding of the patient, then patient needs are neglected and patient outcomes suffer (Knaus et al., 1986; Larson, 1999).

Second, research has shown that adverse events are a result of communication problems (Wilson, Runciman, Gibberd, Harrison, & Hamilton, 1995). For example if the physician is concerned as in the pancreatitis case with alcohol withdrawal and does not relate this information to the nurses, the nurses may not monitor for delirium tremors which can be a significant medical event in alcohol withdrawal, and therefore may not take preventative action in the event the patient has a seizure. Or if the nurses do not inform the physician about the pain status of the patient and the effectiveness of the morphine ordered, the patient may suffer needlessly. Sharing information between groups of clinicians in healthcare is imperative since it can have an impact on the outcome of the patient. It is clear that the same display of information creates more different than the same mental model of the patient, however, I hypothesize that these differences are not due to the information display but to the differences in background knowledge, education and tasks of the clinicians.

Different Displays of Same Information

The hypothesis that the different displays of the same information leads to different mental models among the same types of clinicians was only partially verified.

Within the nursing group, there were no significant differences between the number of propositions and the time it took to complete the cases. There were additionally no significant differences in the amount of information included by the nurses in their summaries from a particular section of the mock medical. Yet differences were noted between the amounts of highlighted information included in the summaries between the highlighted and non-highlighted cases. This is discussed in detail in the next section.

There was additionally a large variance in the number of different concepts included by the nurses within their summaries of the patients. For example, in the pancreatitis non-highlighted case, the nurses included a total of 54 different concepts with only 9 (17%) of these in agreement by $\geq 50\%$ of the nurses. This large variance was noted within the nursing group in all of the cases as specified in the results section. However, upon examining the differences between the concepts in the same highlighted and non-highlighted cases, there was even a smaller subset of agreed upon concepts by $\geq 50\%$ of the nurses. Using the pancreatitis case as an example again, of the 54 different concepts included in the non-highlighted case and 75 different concepts included in highlighted case, 9 (17%) were in agreement in non-highlighted case by $\geq 50\%$ of the nurses and 10 (19%) were in agreement in the highlighted case by $\geq 50\%$ of the nurses. Furthermore, upon delving into the agreement in concepts between the different displays of the same cases by $\geq 50\%$ of the nurses, there was even a smaller subset of concepts in agreement. Between the two different displays of the same information in the pancreatitis cases, only 6 of the concepts were in agreement within the nursing group. This small subset included demographic information, chief complaint of the patient, current medications, patient functional status such as inability to eat, IV information, and

physiological status such as vital sign information. The same variance was noted in the gastroenteritis cases, where only 7 concepts were in agreement between the different display formats. Since the conceptual variance within this group was very large overall, and a large amount of the conceptual variance was created by only a few of the subjects, it made sense to only examine the conceptual agreement and differences made by $\geq 50\%$ of the nurses. The conceptual disagreements were not thought entirely to be due to the displays of information because there was not a consistent difference in the amount or type of disagreed upon concepts within both of these cases. For example in the pancreatitis case, although there was disagreement between 7/13 concepts mentioned by $\geq 50\%$ of the nurses, three of these concepts were from the non-highlighted case and four of these concepts were from the highlighted case. The same was basically true with the gastroenteritis cases within the nursing group. These large conceptual variances within the nursing group were only noted overall within the physician group.

Although it appears that the highlighting of information affected the nursing group overall as evidenced by their large inclusion of highlighted concepts and their verbalization of the importance of the highlighting, it appears that content was more important than the highlighting since there was not a statistically significant difference between the amount of highlighted information included in the nursing summaries generated from the highlighted and non-highlighted cases.

Within the physician group, the differences in the number of propositions, the time to complete the cases, the conceptual differences, and the influence of the display formats between the cases were less apparent. Overall within the physician group, there were no statistically significant differences between the time it took to complete the cases

and the number of propositions included within their summaries between the different displays of the same information. Although there were some statistical differences in the amount of information included by the physicians in their summaries from a particular section of the mock medical, there was for the most part conceptual agreement by $\geq 50\%$ of the physicians.

Within this group as well, there was a large amount of variance regarding the different concepts included in their summaries. For example in the non-highlighted pancreatitis case there were a total of 155 different concepts with only 12 (8%) in agreement by $\geq 50\%$ of the physicians and in the highlighted pancreatitis case, there were a total of 134 different concepts with only 12 (9%) in agreement by $\geq 50\%$ of the physicians. This large variance was consistent in the gastroenteritis cases as well. Yet regardless of this large amount of variance within the group as a whole, there was less variance within the concepts between the different displays of the same case information agreed upon by $\geq 50\%$ of the physicians. For example, in the pancreatitis case there were a total of 13 different concepts included by $\geq 50\%$ of the physicians in the highlighted and non-highlighted cases. Yet there was agreement in 11/13 of these concepts. In the gastroenteritis case, there were a total of 19 different concepts included by $\geq 50\%$ of the physicians, yet 14/19 of these concepts were in agreement. Yet, there was no apparent consistency within these differences between the highlighted and non-highlighted cases. Although there was large variance within the physician group as a whole, there was more conceptual consistency within the subset of $\geq 50\%$ of the physicians than with the nursing subset.

Two questions need to be addressed here. Why is there such a large amount of variance within the groups and how might this variance impact patient care?

The large amount of variance in the concepts presented by the nurses may have been slightly affected by the presence of salient cues such as highlighting, however, the variance within the physicians were not affected by this factor at all. Overall, in the nursing summaries, there was a larger proportion of highlighted information included in the summaries from the highlighted cases than from the non-highlighted cases, although this difference was not statistically significant. In the physician group these differences were less apparent. Overall, there were no statistical differences between the amount of highlighted versus non-highlighted information included in all of their summaries and as a matter of fact they proportionally included in their summaries the exact same amount of highlighted information regardless of display type. It is hypothesized that two factors may have impacted the variance within the physician and nurse cases.

It is strongly speculated that the two other factors that may have had a stronger influence on the variance were levels of expertise within the clinician groups and the cognitive factor of human memory. Differences in the level of expertise were noted within the nursing and physician group. In the nursing group and physician group, the level of expertise is reflected by their respective years in the practice. In the physician group, 12/24 of the physicians were resident physicians in training, and in the nursing group, their years in practice varied from 5 to 32 years. Research in the area of expert vs. novice problem solving in medicine (Groen & Patel, 1991), nursing (Benner, 1984), chess (Charness, 1991), and physics (Anzai, 1991) shows that experts were not only able to concentrate on important patterns in the information, but demonstrated superiority in

avoiding irrelevant information. The novices are not always able to separate the relevant from the irrelevant cues (Groen & Patel, 1991). This would certainly explain the overall large variance in the number of different concepts included by the physicians and nurses within all of the cases. The irrelevant information was mainly the information not included by $\geq 50\%$ of the physicians and nurses. Although not controlling for level of expertise was a delimitation in this study, this factor was not controlled for due to potential recruitment concerns. This particular issue will need to be addressed further in future studies.

The other factor that may have contributed to the large amount of variance within the cases may have been a memory problem. Clinicians are used to working with notes and since they generally do not have to remember large amounts of information, they are not accustomed to building mental models in this fashion. Additionally working memory in humans is a problem. Working memory refers to information that is currently being used or has been recently used, but only lasts for a short duration, and is generally confined to 5 to 7 chunks of information (Proctor & Vu, 2003). This 5 to 7 chunks of information was first described by Miller (1956) in which he found that the memory is not a function of the number of items, but of the number of chunks of information (Miller, 1956). One of the problems with working memory is potential cognitive overload. Since short-term memory is limited in its capacity as described by Miller (1956), it is also possible to overload its capacity with too much or too complex information within a short time frame, which results in, decreased performance. Jacko (1997) conducted an experiment in task complexity and found that each added increasing

level of complexity imposed upon the subject, decreased the subject's performance due to cognitive overload.

The variability of the human information processing system permits us to draw extensive generalizations regarding how individuals act in response to cognitive tasks. Although there are many differences within individuals, I speculate that memory and level of expertise were both factors in the large variation in the conceptual differences of the clinicians.

While the differences within the clinician types may be attributed to display format differences, levels of expertise, and memory problems, the conceptual similarities are reflective of their respective practice models. Whereas the nursing model of the patients within both cases centered on demographic information, current functional status of the patient, current medications and IV information, the medical model of the patient provided a more complex representation which not only included the demographic information, current functional status of the patient, and current medications, but additionally more past medical history information, precipitating events, differential diagnoses, and a treatment and management plan. Since the physician's main tasks are to problem-solve, diagnose, and decide on a plan of treatment, they are primarily more interested in the patient's chief complaints, past medical history, medication history, and history of present illness. While the nursing tasks focus on their care of the patient. Although they share some information, neither is a subset of the other, and is basically reflective of their tasks as shown here in the comparison of the different displays of the same information.

Salient Cues

From the results of the statistical analysis and comments made from the subjects, the use of salient cues such as the highlighting used in this experiment had some negative and positive effects. On the one hand, the nurses commented that the highlighting was helpful in their review of the cases. They thought that the highlighted information quickly separated the important from the unimportant information. This was an assumption since they were not told that the highlighted information was more important than the non-highlighted information. On the other hand, the physicians found the highlighting distracting and were very concerned that they would miss important non-highlighted information. The physician's perception was that their review and summary of the highlighted cases took longer than the non-highlighted cases. When in reality on the average, the physicians took approximately 9.5 minutes to review and summarize both the highlighted and the non-highlighted cases. Although overall the nurses took less time than the physicians to review and summarize the cases, they actually took on the average slightly longer to review the highlighted cases (7.08 minutes) vs. the non-highlighted cases (6.87 minutes). Additionally, the nurses consistently included proportionally more highlighted information in their summaries than the physician included in their summaries. Overall in the nurse summaries, the nurses included on the average 61% of the highlighted information in their summaries. Whereas, overall the physicians proportionately included only 31% of the highlighted information in their summaries. While it could be argued that these differences are due to the fact that the physicians included a larger amount of other types of propositions that would not be considered highlighted information such as interventions and essentially driving the percentage of

highlighted propositions down. However, when only the highlighted versus non-highlighted recalls were examined, the differences between the physicians and nurses were still statistically significant ($p < .001$)

A comparison of the highlighted vs. non-highlighted information included in the physician and nurse summaries by case showed some differences. For example in the non-highlighted versus highlighted case, the nurses included slightly more highlighted information from the highlighted case than from the non-highlighted case (58% versus 65%). The difference was not statistically significant. The physicians showed no significant differences between the amount of highlighted information they included in all of the highlighted versus non-highlighted cases.

The differences between the physicians and nurses can be explained through highlighting validity (Fisher & Tan, 1989). Highlighting validity is the degree that an individual believes that the highlighting is relevant and valid. The physician's concern about the relevancy of the highlighted versus non-highlighted information may have also caused some concern regarding decision-making bias. Therefore, they may not have given this information any more weight than the non-highlighted information. The nurses however, directed their focus on highlighted information to attain their goal. Wickens (2000) states that highlighting can be used to attract visual attention and Hammer (1999) proposes that it conveys the message that this information should be paid attention to. The nurses appeared to have considered this information more important than the non-highlighted information. These findings show a mixed effect of both positive and negative consequences for both the physicians and nurses. The positive effect is that highlighting appears if at the very least perceptively attract attention to

information and thus can be used to attract attention to significant results such as laboratory results. The negative effect is that if too much information is highlighted, relevancy of the highlighted information will be questioned regarding its validity and, therefore should be used with caution. In the area of medicine where problem solving and decision-making are critical to the outcome of the patient, it is important the use of salient cues and placement of information are compatible with the tasks of the clinician and do not impose unnecessary noise or distraction potentially altering the information processing and thus decision-making of the clinician.

Limitations

Understanding mental models that a person uses to comprehend or organize new information has been difficult to analyze and assess. There are several limitations with this study.

First elicitation techniques such as verbal protocols in a highly directive and artificial environment such as the laboratory may either misrepresent or influence the processes it purports to capture (Ericsson & Simon, 1984). However, think-aloud solving of simulated problems is considered only somewhat directed and somewhat unnatural. The subjects, although not in their natural environment were being asked to complete a task that is as close to their natural task as possible. Since presenting these clinical data in a meaningful context, I think it is reasonable to believe that the thinking-aloud is reflective of their true clinical thinking. However, it must be kept in mind that there may be some biases in these data since the clinicians were not in their natural environment. Additionally the clinicians are used to working with notes and not directly from memory, which may account for some of the noise in these data.

Second, practice years were not controlled for in the recruitment phase due to the difficulty of recruiting clinicians, especially the physicians. So, there are some differences in the practice years both within and between the groups of clinicians. Within the physician group, 12 out of the 24 physicians recruited to this study were residents and fellows in training and within the practicing physician subgroup, the practice years ranged from 1 to 29 years. Additionally, there were differences within the nursing group in terms of years of experience, which, ranged from 5 to 32 years. These differences were not separated out in these data because the number of subjects in each subgroup would have been reduced to the maximum of 6 subjects per case, and this would not have allowed testing for statistical significance. Also due to the variance of practice years within the nurse group and large variance within the physician group, there was no way to compare the two groups by practice years between the nurses and physicians. However, these data were reviewed in general within the nursing group and the physician group, separating each group by practice years, and no large differences were found in terms of types and number of propositions. It should be kept in mind that different types of clinicians, physicians and nurses, and different individuals within each group may differ in the knowledge they possess and the strategies they use to problem-solve regardless of the years in practice.

Third, there was no inter-rater reliability performed to confirm the consistency of the coding of the propositions in the summaries of the cases. Although these data were reviewed several times until it was determined that no other changes could be made or to the point of saturation, validity and reliability could still be questioned since there wasn't

a review of the coding by an outside reviewer. Internal consistency is important to the validity and reliability of the data.

Finally, there was also some variance in the education levels between the nurses, which, was not controlled for in the recruitment phase as well. This was separated out in the initial data analysis phase as well and no significant differences were found within the nursing group.

The differences in the education level, years in practice, and inability to work from notes may have been some of the reasons for the variance in these data both within and between these groups of clinicians. It is suggested that further study in this area needs to control for these factors.

Implications for Health Informatics

In the current era, of advancing information technology, healthcare providers will be challenged with increasing complex levels of information, and therefore will have a greater need to utilize technologies to efficiently manage such information. Their ability to easily adopt and implement these technologies will depend upon their access, their experience, and their use of these tools. Information technology has the potential to assist clinicians with the development of the right mental model for the task at hand.

Facilitating the development of the right mental model clinicians need to develop for problem-solving and decision-making can be assisted through the use of information technology, however, this requires us to understand how clinicians mentally represent information and how they use this information to diagnose, manage, treat and care for patients. The implications for the results of this research study lay in the future design of the electronic medical records.

According to a recent report issued by the Institute of Medicine (2001), the quality of our healthcare delivery system in America today is substandard and the relative absence of an information infrastructure is partly to blame. A healthcare information infrastructure shows great promise in potentially improving the quality of care through decreasing errors, increasing efficiency and quality of healthcare (Institute of Medicine, 2003). Although this technology offers the potential to positively impact the quality of our healthcare, the implementation of computerized information systems in healthcare has been painfully slow since the 1991 Institute of Medicine report that identified electronic patient records as an “essential technology” and called for the eradication of the paper records within 10 years (Institute of Medicine, 1991). There are several reasons why there has not been widespread adoption of electronic health records. On the one hand, there have been financial, organizational, and technological problems (Overhage, Middleton, Miller, Zielstorff, & Hersh, 2002). On the other hand, a deficiency of user-centered interfaces has been cited as a major obstacle to acceptance and standard use of healthcare information systems (Tang & Patel, 1994; Lun, 1995; Coble, Karat, Orland, & Kahn, 1997; Terazzi, Giordano, & Minuco, 1998). These deficiencies primarily stem from a lack of understanding of the cognitive needs of the users, and a failure to fully take into account human-computer interaction (Tang & Patel, 1994). Patel and Kushniruk (1998) propose that more basic research is needed in understanding the user, their work activities and reasoning processes to adequately address the cognitive needs of the user. To begin to understand the cognitive needs and the human-computer interaction, I have focused on three interacting components, the user, their tasks, and the representation of the problem information. Specifically, I have examined how the

different backgrounds and tasks of physicians and nurses interact with different and same displays of information to affect mental models. Understanding how the different displays of information can affect comprehension and decision-making provided insight into the cognitive processes of clinicians and thus provided some results that may assist in the process of designing ideal medical interfaces, such as the use of salient cues and the order of placement of important patient information.

Success in problem solving can be, at least partially, explained by the quality of the mental models of the problem-solver (Gott, Bennett, & Gillet, 1986). Internal representations such as mental models were studied because they are vital in understanding both comprehension and problem solving. For example, if two people internally represent the same information in dissimilar ways, then their model of the problem and possibly their solution of the problem may be dissimilar. Understanding effective and ineffective models will thus provide guidance for designing ideal interfaces that should be included in medical environments to support effective mental model development.

The electronic medical record serves many purposes in addition to providing a collection of facts about a patient's health. It serves as a medium of communication between groups of practitioners, ensures continuity of care, and provides medico-legal coverage (Pincioli, Crippa, Combi, Reni, & Fava, 2000). Yet this medium of communication is fraught with problems. There is often conflicting and redundant information, navigation problems, organizational problems, illegibility, and poor availability (Gordon, Geiger, Lowe, & Jickling, 1998; Tuttle, Cole, Sherertz, & Nelson, 1995; Tange, 1995). Much of the design of the electronic medical record has been

modeled after the paper record and hence does not use the power and options available with the electronic technology. The medical record should provide an opportunity for improving patient care and not decrease clinical efficiency and add to the cost of clinical care. These records perform a significant role in not only gathering and storing information but also in supporting medical work (Berg, 1999). In essence these records are not just repositories of patient health information, but are influential in problem solving and decision-making. This point should be carefully taken into consideration in view of the design of the EMR. The record needs to support the work of the clinicians and not impede the process of care or generate extra tasks that deplete cognitive resources.

Electronic medical records need to be designed to its goals and the goals of the users. Although it needs to contain certain necessary information, the information needs to be presented in a manner that mimic the thought processes, work routines, and practices of the users (Goorman & Berg, 2000). Health care is a heterogeneous environment where there are many types of clinicians and not all share the same information space. Although the concept of a “Common Information Space” (Bannon & Bodker, 1997) is appealing, it is not practical since the nursing staff and the physicians have different viewpoints of the patient.

The need for a good design model for the electronic medical record is apparent, and although there may be a commonality of information between clinician types, the representation of this shared and unshared information needs to support the respective clinician type. It is clear from this research presented here that physicians and nurses have more unshared information than shared information due to the differences in their

backgrounds and tasks. These data confirm that a common information space is not practical to the individual tasks of the clinicians and may even hamper their efforts. These results suggest that what the nurses and physicians need are different views of patient information that specifically focus on the tasks of their profession. Although there may create some redundancy of information within the electronic medical record, given the fact that these records are created with relational databases, it should not create discrepancies within these patient data. The most important finding was the impact the use of highlighting had on the mental models of the nurses. Although the use of highlighting did not appear to impact the physicians objectively they subjectively disagreed with its presence fearing that they may miss important non-highlighted information. Therefore, color-coding needs to be used judiciously within the electronic medical record.

Conclusions

The primary goal of this research was to study how the different backgrounds and tasks of physicians and nurses interact with different and same displays of information to affect mental models. The results from this study suggest that although the differences in the background knowledge, training and tasks of the physicians and nurses can account for some of their differences in their comprehension of patient information, the effects of information displays on perception, comprehension, and reasoning can additionally affect their comprehension. My two hypotheses proposed within this research were verified in part and nullified in part. The results of this research provided several interesting insights and conclusions.

First, the hypothesis that the same information display will lead to different mental models among different types of clinicians was verified. Second, the hypothesis that different displays of the same information will lead to different mental models within the same clinician type was verified in part within the nursing group and nullified in the physician group. Third, the effect of the display formats appeared to affect the information generated in both the nursing and physician summaries. Finally, the use of only recalls and inferences to categorize propositions for analysis within the clinician summaries was not adequate to reveal the complexities within their summaries. This research presents a new coding scheme that satisfactorily represented all of their propositional types and thus was able to portray a more comprehensive understanding of clinician mental models.

The first and second conclusions provided direct insight into how the use of salient cues such as the highlighting used in this study could affect or not affect the development of mental models between different types of clinicians. The nurses on the one hand, assumed that the highlighted information conveyed importance and although they proportionately included more highlighted information in their summaries than the physicians who were more reticent to believe the sole importance of this information, statistically there was no difference in the amount of highlighted information each group included in their summaries from both the highlighted and non-highlighted cases. Since highlighting validity (Fisher & Tan, 1989) as in this case can impact what information is attended to, caution needs to be exercised when deciding on the use of salient cues in information displays. This is even more critical in the area of medicine whereby problem

solving and decision-making based on information attended to can affect patient outcomes in potentially negative ways.

The first conclusion that the same information display will lead to different mental models among different types of clinicians verified the significance of the interaction between the background, tasks, and display of information to affect the development of mental models. Overall, the different types of clinicians had different mental models of the patient with some minor shared information. The shared information represented patient demographics, habit information, current medications, and some minor history of present illness information. The differences shown between the nurses and physicians were more reflective of the differences in their background and tasks, than due to the display of information. The overall diversity and variance of concepts included in the summaries could be attributed to three factors. First, the individual limitations of working memory (Proctor & Vu, 2003) may have affected the variance in the concepts included by the clinicians. Second, since mental models are based upon collections of knowledge, it is expected that different clinicians would include different conceptual views of the patient. Third, it was shown that the highlighted information did impact the nurses in this study. Zhang proposes that external representations can establish the direction the mind functions around a task (Zhang, 1997). That was certainly true with the models the nurses constructed. Although the same information displays lead to different yet a minor shared mental model between clinician types, it is strongly suggested that the background and tasks of the clinicians was more influential in shaping their mental models.

The second conclusion that different displays of the same information will lead to different mental models within the same clinician type was verified in part within the nursing group and nullified in the physician group. The physicians were fairly consistent in their mental models between the different displays of information as reflected in their consensus of concepts included in their summaries. There was however, a larger amount of variance within the nursing conceptual understanding of the patients with the different displays of the same information. This variance was thought to be due to the different displays of information as well as the confounding variable of differences in levels of expertise. Although the confounding factor of expertise is purely speculative, it will require further study in this area to prove or disprove this hypothesis.

Finally, this study proposes a new conceptual framework for categorizing clinical information. The addition of assumptions, conditionals, negatives, and interventions to the proposed coding of recalls and inferences provided a more rich understanding of how clinicians comprehend patient information and reason. It also helped to show the differences in the practice models of the physicians and nurses.

This study provided evidence the background, training, and tasks of the clinicians played a significant role in their perception, comprehension, and reasoning when confronted with new patient information. Whereas the nursing mental models were more directly impacted by the different displays and were a direct reflection of their tasks, the physician mental models were less impacted by the different displays of information and overall contained a more diversified and complex representation of the patient.

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Appendix A: CPHS Approval



THE UNIVERSITY of TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

THE COMMITTEE *for the* PROTECTION of
HUMAN SUBJECTS

322 Jesse Jones Library Building 713 500 5827
P.O. Box 20036 713 500 5830 fax
Houston, Texas 77225
Cynthia.L.Edmonds@uth.tmc.edu

NOTICE OF APPROVAL TO BEGIN RESEARCH

February 13, 2002

HSC-SAHS-02-001 – “Effects of Information Display on the Construction of Clinician Mental Models”

PI: Constance M. Johnson, RN, Ph.D.

PROVISIONS: Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consent, etc.

APPROVED: At a Convened Meeting

APPROVAL DATE: January 18, 2002

EXPIRATION DATE: December 31, 2002

CHAIRPERSON: Anne Dougherty, MD

Subject to any provisions noted above, you may now begin this research.

CHANGES – The PI must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT – Informed consent must be obtained by the PI or designee using the format and procedures approved by the CPHS. The PI must instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document.

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS – The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS – The PI will maintain adequate records, including signed consent documents if required, in a manner which ensures confidentiality.



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Houston, Texas 77225
Cynthia.L.Edmonds@uth.tmc.edu

NOTICE OF APPROVAL TO IMPLEMENT REQUESTED CHANGES

November 15, 2002

HSC-SHIS-02-001 "Effects of Information Display on the Construction of Clinician Mental Models"

PI: Constance Johnson, Ph.D. Candidate

PROVISIONS: Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consents, etc.

NOTE: In reference to memo(s) dated October 28, 2002

APPROVED: At a Convened Meeting

APPROVAL DATE: November 15, 2002

CHAIRPERSON: Anne Dougherty, MD

Upon receipt of this letter, and subject to any provisions noted above, you may now implement the changes approved at this meeting.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. **Please note that if revisions to the informed consent form were made and approved, then old copies of the ICF MUST be destroyed. Only copies of the appropriately dated, stamped approved informed consent form can be used when obtaining consent.**

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner that ensures subject confidentiality.



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NOTICE OF APPROVAL TO IMPLEMENT REQUESTED CHANGES February 24, 2003

HSC-SHIS-02-001 – "Effects of Information Display on the Construction of Clinician Mental Models"
PI: Constance M. Johnson, RN, Ph.D.

PROVISIONS: Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consent, etc.

NOTE: In reference to memo(s) dated February 10, 2003

APPROVED: At a Convened meeting

APPROVAL DATE: February 21, 2003

CHAIRPERSON: Anne Dougherty, MD

Upon receipt of this letter, and subject to any provisions noted above, you may now implement the changes approved at this meeting.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. **ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.**

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. **Please note that if revisions to the informed consent form were made and approved, then old copies of the ICF MUST be destroyed. Only copies of the appropriately dated, stamped approved informed consent form can be used when obtaining consent.**

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner that ensures subject confidentiality.



THE UNIVERSITY of TEXAS
HEALTH SCIENCE CENTER AT HOUSTON

THE COMMITTEE for the PROTECTION of
HUMAN SUBJECTS

322 Jesse Jones Library Building 713 500 5827
P.O. Box 20036 713 500 5830 fax
Houston, Texas 77225

NOTICE OF CONTINUING REVIEW APPROVAL

February 26, 2003

HSC-SHIS-02-001 – “Effects of Information Display on the Construction of Clinician Mental Models”

PI: Constance M. Johnson, RN, Ph.D.

PROVISIONS: Unless otherwise noted, this approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consents, etc.

APPROVED: At a Convened Meeting

APPROVAL DATE: February 21, 2003

EXPIRATION DATE: November 30, 2003

CHAIRPERSON: Anne Dougherty, MD

Upon review, the CPHS finds that this research is being conducted in accord with its guidelines and with the methods agreed upon by the principal investigator (PI) and approved by the Committee. This approval, subject to any listed provisions and contingent upon compliance with the following stipulations, will expire as noted above:

CHANGES: The PI must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. **ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.**

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. Attached is the approved and validated informed consent form. You must discard all previous informed consent documents being used and replace them with this stamped validated version. **Please note that only copies of the appropriately dated, stamped approved informed consent form can be used when obtaining consent.**

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner which ensures subject confidentiality.

Located in the Texas Medical Center

Appendix B: Data Collection Instrument

Effects of Information Display on the Construction of Clinician Mental Models

Data Collection Form

Principal Investigator: Constance Johnson, M.S., R.N.

University of Texas – Houston Health Science Center

School of Health Information Sciences

Date of Experiment: _____

Gender: Male Female

Age: _____

Education Level: Associates Bachelors Masters PhD MD

Occupation: RN MD

Number of Years In Practice: _____

Notes:

Time Started Test Case1: _____

Test Case Number One: Case _____

Time Ended Test Case 1: _____

Notes Case 1:

Time Started Test Case2: _____

Test Case Number Two: Case _____

Time Ended Test Case 2: _____

Notes Case 2:

Training Case 3:

Notes Case 3:

Total Time: _____

Appendix C: Example of RN Highlighted Case

Microsoft Access - [frmMain : Form]

File Edit View Insert Format Records Tools Window Help

Tahoma 10 B I U

Type a question for help

Demographics

HPI

History/Habits

Medications

Allergies

Review Of Systems

Vital Signs

Input/Output

PE: Eye/ENT/Neck

PE: Resp/CV/GI

PE: GU/Lymph/MSK

PE: Skin/Neuro/MSE

Nursing Notes

Assessment

Physician Orders

Done

Select Patient

Case 1HL

PHYSICAL EXAM: EYE/ENT/NECK

General
 Flushed facies, generalized tremor, extremities cool

Eyes
Conjunctivae and lids: conjunctivas are injected
Pupils: equal, round, reactive to light and accommodation
Ophthalmoscopic: discs sharp and flat, no a/v nicking, hemorrhages, or exudates
Sclera: nonicteric

Ears/Nose/Throat
Hearing: grossly intact
Nasal passages: mucosa, septum turbinates normal
Dental: poor dentition
Pharynx: tongue dry, posterior pharynx without erythema

Neck
Neck: supple, no masses, trachea midline
Thyroid: no nodules, masses, tenderness, or enlargement

Form View

Appendix D: Example of MD Highlighted Case

Microsoft Access - [frmMain : Form]

File Edit View Insert Format Records Tools Window Help

Tehoma 10 B I U

Type a question for help

Demographics

HPI

History/Habits

Medications

Allergies

Review Of Systems

Vital Signs

Input/Output

PE: Eye/ENT/Neck

PE: Resp/CV/GI

PE: GU/Lymph/MSK

PE: Skin/Neuro/MSE

Nursing Notes

Assessment

Physician Orders

Done

Select Patient

Case 1HL

PHYSICAL EXAM: EYE/ENT/NECK

General
 Flushed facies, generalized tremor, extremities cool

Eyes
Conjunctivae and lids: conjunctivas are injected
Pupils: equal, round, reactive to light and accommodation
Ophthalmoscopic: discs sharp and flat, no a/v nicking, hemorrhages, or exudates
Sclera: nonicteric

Ears/Nose/Throat
Hearing: grossly intact
Nasal passages: mucosa, septum turbinates normal
Dental: poor dentition
Pharynx: tongue dry, posterior pharynx without erythema

Neck
Neck: supple, no masses, trachea midline
Thyroid: no nodules, masses, tenderness, or enlargement

Form View

Appendix E: Recruitment Poster

PRACTICING REGISTERED NURSES AND PHYSICIANS WITH A BACKGROUND IN GASTROINTESTINAL MEDICINE NEEDED FOR RESEARCH STUDY

Goal of Research: To determine if the display of information affects the decisions physicians and nurses make about patient care.

Procedure: You will be asked to review three cases in different formats displayed on a computer screen and talk out loud as you review and summarize the cases. Your voice and the computer screen will be recorded. Your face will not be recorded. You will be compensated for your time.
Total Time Required: 1 hour

Where: UCT Building, UT School of Health Information Sciences

If interested call: Constance Johnson at 713-500-3456 or email
Constance.M.Johnson@uth.tmc.edu

UT Committee for the Protection of Human Subjects Approval
(HSC-SAHS-02-001)

Appendix F: Consent to Participate in Experiments

TITLE: Effects of Information Display on the Construction of Clinician Mental Models
CPHS # HSC-SAHS-02-001

INVITATION TO TAKE PART: You are being invited to take part in a research project called, “Effects of Information Display on the Construction of Clinician Mental Models” conducted by Constance Johnson, M.S., R.N., Ph.D. Candidate. Your decision to take part is voluntary and you may refuse to take part, or choose to stop taking part, at any time. A decision not to take part, or to stop being a part of this research project will not change the services that are available to you. You may refuse to answer any questions asked or written on any forms.

This consent form explains why we are performing this research study and what your role would be. This form also describes your risks linked with being in this study. After reviewing this information with the primary investigator, you should know enough about this study to be able to make an informed decision on whether you want to be in the study. This study complies with all laws and regulations that apply.

DESCRIPTION OF RESEARCH:

PURPOSE: The goal of this research is to determine if the features in the display of information such as how this information shown to physicians and nurses affects the decisions they make about patient care and management. The results of this research will assist us in identifying important design requirements for the display of computerized patient records.

PROCEDURE: During this study you will asked to review and analyze a total of three medical cases in an electronic medical record format. You will be asked to ‘talk aloud’ as you review and analyze each case on a computer screen. This means we would like you to say out-loud everything you are thinking or would normally say to yourself. Everything you say out-loud will be recorded onto the audio track of videotape. After you finish reviewing each case, we will ask you to dictate a summary of the case. The computer screen on which we will be reviewing the cases will be videotaped. Your face will not be videotaped. This is an investigational study. About 48 subjects will take part in this study.

The videotapes will be identified only with the accession number. This is necessary in order to review these data at a future date. A list linking the accession number to the subject name will be kept in a locked file until all data are collected.

The medical cases in this study are not real patients and families, but have been constructed by the investigator. No such person actually exists.

TIME COMMITMENT: The process will take about 60 minutes to complete. There will be no further follow-up.

BENEFITS: There are no direct benefits from this study but your participation may lead to a better understanding of how electronic patient records should be structured. This understanding may lead to a more efficient means of recording and representing patient record information.

RISKS AND/OR DISCOMFORTS: The only known potential risk would be breach of confidentiality. This is not believed to present any significant risk.

ALTERNATIVES: There are no alternatives available.

STUDY WITHDRAWAL: Your decision to take part is voluntary and you may refuse to take part, or choose to stop taking part, at any time. A decision not to take part, or to stop being a part of this research project will not change the services that are available to you.

IN CASE OF INJURY: If you suffer any injury as a result of taking part in this research study, please understand that nothing has been arranged to provide free treatment of the injury or any other type payment. However, all needed facilities, emergency treatment and professional services will be available to you just as they are to the community in general. You should report any such injury to Constance Johnson at 713-500-3456 and to the Committee for the Protection of Human Subjects at 713-500-5827.

COSTS, REIMBURSEMENT, AND COMPENSATION: No costs for study participation are anticipated. However, either \$50.00 or an equivalent \$50.00 gift certificate will be provided to you for your participation.

CONFIDENTIALITY: You will not be personally identified in any reports or publications that may result from this study. Any personal information about you that is gathered during the study will remain confidential to every extent of the law. A special number will be used to identify you in the study and only the investigator will know your name.

If you agree to participate in this study, please understand that all information will be anonymous and recorded only using an accession number. The Principal Investigator, Constance Johnson, will keep a list linking accession number to the subject name until all data is collected and that the list will be destroyed as soon as the last subject data is collected. When and if this study is reported only anonymous aggregated data will be presented.

QUESTIONS: You may ask any questions you have about this study at this time or at any future date. You may contact the Primary Investigator, Constance Johnson, MS, R.N., doctoral candidate at 713-500-3456 or her committee chairman, Dr. Todd Johnson at 713-500-3921.

SIGNATURES: Sign below only if you understand the information given to you about the research and choose to take part. Make sure that any questions have been answered and that you understand the study. If you have any question or concerns about your rights as a research subject, call the Committee for the Protection of Human Subjects at (713) 500-5827. If you decide to take part in this research study, a copy of this consent form will be given to you.

Subject Signature

Date/Time

Printed Name of Person Obtaining Consent

Signature of Person Obtaining

This research project has been reviewed by the Committee for the Protection of Human Subjects (CPHS) of the University of Texas Houston Health Science Center as HSC-SAHS-02-001.

Appendix G: Analysis Plan

The main objective of this research is to determine if factors in the display of information affects the mental models constructed by the same and different types of clinicians. The results of this research will provide insight into the mental models constructed by clinicians and will thus assist us in identifying important design requirements for the display of interfaces in the medical domain.

1. Determine the relationship between displays presented to clinicians and the mental models constructed by the clinicians.
2. Construct guidelines for the interface of healthcare applications that parallels the mental models of different clinicians.

Two hypotheses will be tested.

1. The same information display will lead to different mental models among different clinicians.
2. Different displays of the same information will lead to different mental models for the same clinician.

Analysis Plan

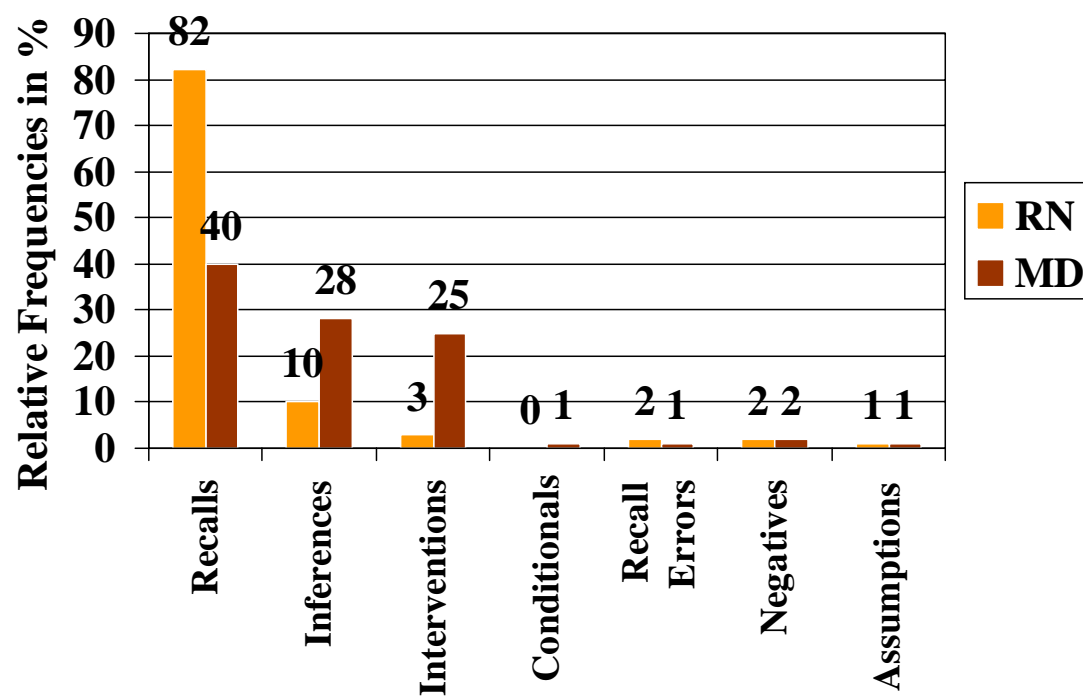
Research Objectives	Independent Variable(s)	Dependent Variable	Analytic Procedure	Tests of Significance
The same information display creates different mental models among different clinicians	Occupation (Nominal)	Case Time (Continuous)	Compare between	MANOVA
	Case (Nominal)	Recalls (Continuous)	subjects (RN+MD)	General Linear Model
		Inferences (Continuous)	C1 vs. C1	
		Errors (Continuous)	C2 vs C2	
		Assumptions(Continuous)	These are stratified	
		Conditionals (Continuous)	by case.	
		Interventions (Continuous)		
		Negatives (Continuous)		
		Propositions (Continuous)		
	Occupation (Nominal)	Case Time (Continuous)	Compare between	
	Case (Nominal)	Recalls (Continuous)	subjects (RN+MD)	
		Inferences (Continuous)	C1HL vs. C1HL,	

	Errors (Continuous)	C2HL vs. C2HL	
	Assumptions(Continuous)	These are stratified	
	Conditional (Continuous)	by case.	
	Interventions (Continuous)		
	Negatives (Continuous)		
	Propositions (Continuous)		
	HLInfo (Continuous)		
Occupation (Nominal)	Concepts (Categorical)	Compare between	Need to assess for
Case (Nominal)	Section (Nominal)	subjects (RN+MD)	agreement by case,
		C1 Vs. C1	subject and
		C2 vs. C2	occupation. Will
		C1HL vs C1HL	use concepts
		C2HL vs. C2HL	included by $\geq 50\%$
			of subjects. Will
			use descriptive
			statistics.

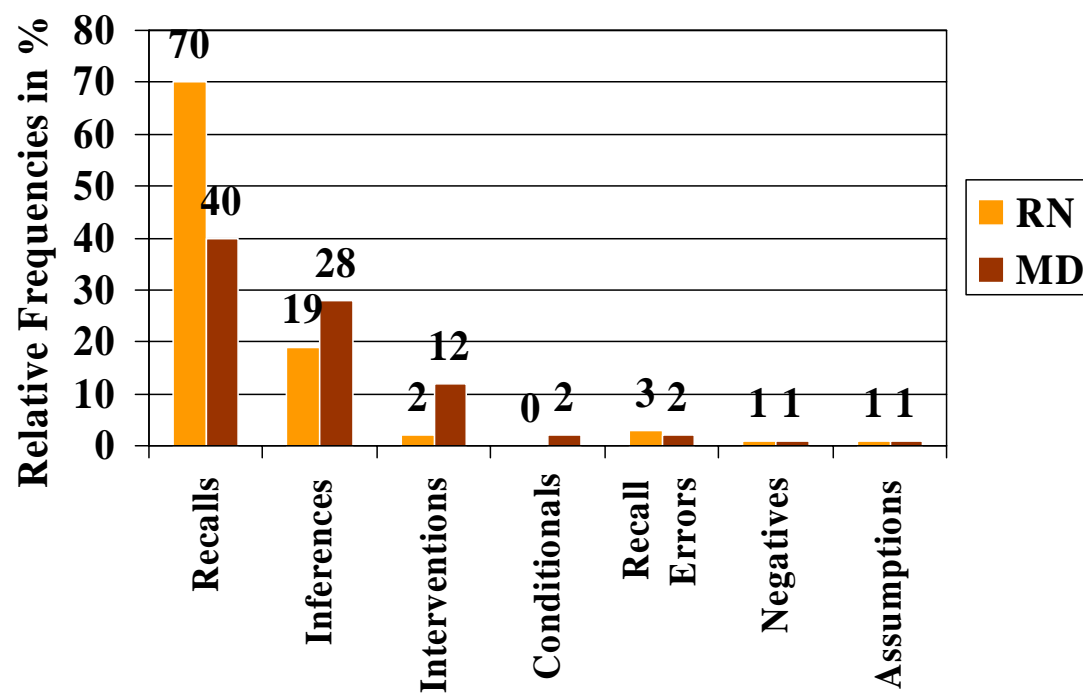
Different displays of	Occupation (Nominal)	Case Time (Continuous)	Compare within	MANOVA
the same	Case (Nominal)	Recalls (Continuous)	subjects (MD and	General Linear
information will		Inferences (Continuous)	RN separately)	Model
lead to different		Errors (Continuous)	C1 vs. C1HL	
mental models for		Assumptions(Continuous)	C2 vs. C2HL	
the same clinician.		Conditionals (Continuous)		
		Interventions (Continuous)		
		Negatives (Continuous)		
		Propositions (Continuous)		
		HLInfo (Continuous)		

Occupation (Nominal)	Concepts (Categorical)	Compare within	Assessment of
Case (Nominal)	Section (Nominal)	subjects (MD and	agreement by case
		RN separately)	and subject within
		C1 vs. C1HL	each occupation
		C2 vs. C2HL	Will use concepts
			included by $\geq 50\%$
			of subjects. Will
			use descriptive
			statistics.

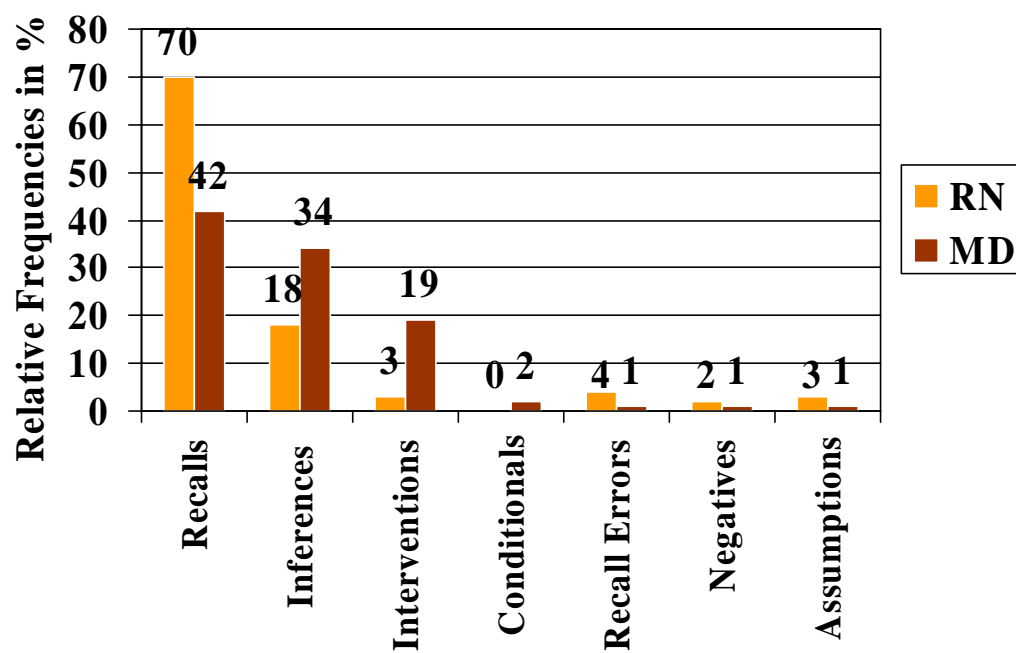
Appendix H: Pancreatitis Non-highlighted Case



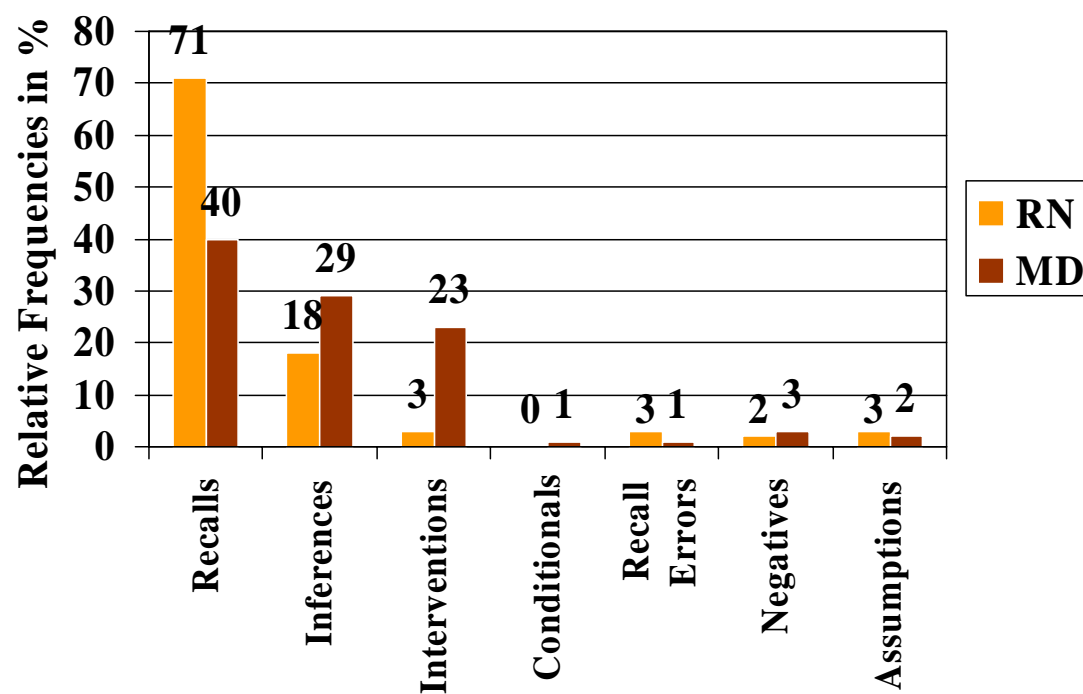
Appendix I: Pancreatitis Highlighted Case



Appendix J: Gastroenteritis Non-highlighted Case



Appendix K: Gastroenteritis Highlighted Case



Appendix L: Propositional Differences Between Physicians and Nurses in Pancreatitis Highlighted and Non-highlighted Cases

Propositional Type	Case C1 ^a RN Mean \pm SD (Range)	Case C1 ^a MD Mean \pm SD (Range)	Case C1 ^a Significance Level (Pr F) 95% CI	Case C1HL ^b RN Mean \pm SD (Range)	Case C1HL ^b MD Mean \pm SD (Range)	Case C1HL ^b Significance Level (Pr F) 95% CI
Recalls	16.50 \pm 6.35 (6-30)	21.83 \pm 22.90 (1-70)	0.445	17.08 \pm 8.88 (2-33)	18.50 \pm 13.48 (2-46)	0.764
Recalls (<i>rf</i>) ^c	0.82	0.40	0.000	0.70	0.40	0.001
Inferences	2.58 \pm 3.90 (0-14)	11.25 \pm 5.96 (3-22)	0.000	4.92 \pm 4.27 (1-16)	11.50 \pm 4.27 (4-19)	0.001
Inferences (<i>rf</i>) ^c	0.10	0.28	0.000	0.19	0.28	0.017
Assumptions	0.25 \pm 0.62 (0-2)	0.67 \pm 1.30 (0-4)	0.328	0.08 \pm 0.29 (0-4)	0.050 \pm 1.00 (0-3)	0.179
Assumptions (<i>rf</i>) ^c	0.01	0.01	0.926	0.01	0.01	0.764
Negatives	0.58 \pm 1.08 (0-3)	1.17 \pm 2.03 (0-7)	0.391	0.33 \pm 0.78 (0-5)	0.50 \pm 1.00 (0-4)	0.653
Negatives (<i>rf</i>) ^c	0.02	0.02	0.987	0.01	0.01	0.946
Interventions	1.0 \pm 1.60 (0-5)	9.25 \pm 4.81 (3-19)	0.00	1.00 \pm 2.00 (0-7)	9.83 \pm 3.27 (2-18)	0.000

Propositional Type	Case C1 ^a RN Mean \pm SD (Range)	Case C1 ^a MD Mean \pm SD (Range)	Case C1 ^a Significance Level (Pr F) 95% CI	Case C1HL ^b RN Mean \pm SD (Range)	Case C1HL ^b MD Mean \pm SD (Range)	Case C1HL ^b Significance Level (Pr F) 95% CI
Interventions (<i>rf</i>) ^c	0.03	0.25	0.00	0.07	.26	0.004
Conditionals	0.00	1.0 \pm 1.54 (0-5)	0.035	0.00 0	0.67 \pm 0.78 (0-2)	0.007
Conditionals (<i>rf</i>) ^c	0.00	0.03	0.017	0.00	0.02	0.017
Errors	0.67 \pm 0.78 (0-2)	0.92 \pm 2.11 (0-7)	0.704	0.75 \pm 0.97 (0-3)	1.08 \pm 1.68 (0-5)	0.557
Errors (<i>rf</i>) ^c	0.02	0.01	0.236	0.03	0.02	0.339
Highlighted Propositions	^d	^d	^d	14.58 \pm 7.73 (2-28) ^e	13.75 \pm 8.25 (2-29) ^e	0.801
Highlighted Propositions (<i>rf</i>) ^c	^d	^d	^d	0.62 ^e	0.31 ^e	0.000

^a C1 = pancreatitis case non-highlighted.

^b C1HL = pancreatitis case highlighted

^c *rf* = relative frequency

^d non-highlighted case

^e highlighted case

Appendix M: Propositional Differences Between Physicians and Nurses in Gastroenteritis Highlighted and Non-highlighted

Propositional Type	Cases					
	Case C2 ^a RN Mean \pm SD (Range)	Case C2 ^a MD Mean \pm SD (Range)	Case C2 ^a Significance Level (Pr F) 95% CI	Case C2HL ^b RN Mean \pm SD (Range)	Case C2HL ^b MD Mean \pm SD (Range)	Case C2HL ^b Significance Level (Pr F) 95% CI
Recalls	15.00 \pm 5.59 (9-29)	17.58 \pm 12.18 (4-44)	0.511	14.58 \pm 5.42 (6-25)	21.33 \pm 22.26 (3-75)	0.32
Recalls (<i>rf</i>) ^c	0.70	0.42	0.000	0.71	0.40	0.000
Inferences	3.83 \pm 2.03 (0-7)	12.58 \pm 6.05 (5-28)	0.000	4.00 \pm 3.36 (1-12)	12.08 \pm 6.01 (6-23)	0.000
Inferences (<i>rf</i>) ^c	0.18	0.34	0.000	0.18	0.29	0.01
Assumptions	0.583 \pm 0.792 (0-2)	0.25 \pm 0.45 (0-1)	0.219	0.67 \pm 1.15 (0-4)	1.08 \pm 1.16 (0-3)	0.39
Assumptions (<i>rf</i>) ^c	0.03	0.01	0.09	0.03	0.02	0.47
Negatives	0.583 \pm 1.08 (0- 3)	0.583 \pm 1.08 (0- 3)	1.0	0.75 \pm 1.48 (0-5)	1.25 \pm 1.46 (0-4)	0.42
Negatives (<i>rf</i>) ^c	0.02	0.01	0.448	0.02	0.03	0.93
Interventions	0.750 \pm 1.48 (0- 5)	6.75 \pm 3.96 (1-16)	0.000	0.83 \pm 1.75 (0-5)	9.33 \pm 4.75 (2-18)	0.000

Propositional Type	Case C2 ^a	Case C2 ^a	Case C2 ^a	Case C2HL ^b	Case C2HL ^b	Case C2HL ^b
	RN Mean \pm SD	MD Mean \pm SD	Significance	RN Mean \pm SD	MD Mean \pm SD	Significance
	(Range)	(Range)	Level (Pr F)	(Range)	(Range)	Level (Pr F)
			95% CI			95% CI
Interventions (<i>rf</i>) ^c	0.03	0.19	0.000	0.03	0.23	0.000
Conditionals	0	0.666+ 1.07	0.043	0.00	0.42 \pm 0.67	0.04
		(0 - 3)			(0-2)	
Conditionals (<i>rf</i>) ^c	0.00	0.02	0.034	0.00	0.01	0.06
Errors	0.666 \pm 0.887	0.583 \pm 0.90	0.822	0.58 \pm 0.67	0.92 \pm 1.62	0.52
	(0- 2)	(0- 3)		(0-2)	(0-5)	
Errors (<i>rf</i>) ^c	0.02	0.01	0.158	0.03	0.01	0.27
Highlighted	^d	^d	^d	13.67 \pm 5.28	13.50 \pm 8.85	0.96
Propositions				(8-23)	(2-29)	
Highlighted	^d	^d	^d	0.67	0.31	0.000
Propositions (<i>rf</i>) ^c						

^a C2 = gastroenteritis case non-highlighted.

^b C2HL = gastroenteritis case highlighted

^c *rf* = relative frequency

^d non-highlighted case

Appendix N: Conceptual Differences between Nurses and Physicians in Pancreatitis

Cases (Highlighted and Non-highlighted)

Concept	Case C1 ^a	Case C1 ^a	Case C1HL ^b	Case C1HL ^b
	# of RN	# of MD	# of RN	# of MD
	Subjects (%)	Subjects (%)	Subjects (%)	Subjects (%)
	(Total #) ^c	(Total #) ^c	(Total #) ^c	(Total #) ^c
Morphine	8 (67%) 9	0	5 (42%) 6	0
IV	11 (92%) 14	4 (33%) 6	9 (75%) 13	3 (25%) 4
Can't eat	7 (58%) 9	5 (41%) 7	6 (50%) 8	5 (41%) 9
Tremors	3 (25%) 3	6 (50%) 9	4 (33%) 6	2 (17%) 4
Tobacco	6 (50%) 11	6 (50%) 9	5 (41%) 12	7 (58%) 8
Medications	10 (83%) 19	7 (58%) 18	9 (75%) 21	10 (83%) 27
Pancreatitis	0	9 (75%) 20	1 (08%) 1	11 (92%) 18
Gastritis	5 (42%) 6	9 (75%) 17	6 (50%) 8	10 (83%) 17
Alcohol	6 (50%) 12	9 (75%) 16	4 (33%) 7	11 (92%) 22
Nausea	3 (25%) 4	9 (75%) 13	5 (42%) 5	8 (67%) 12
Vomiting	9 (75%) 14	10 (83%) 21	9 (75%) 15	8 (67%) 13

Concept	Case C1 ^a	Case C1 ^a	Case C1HL ^b	Case C1HL ^b
	# of RN	# of MD	# of RN	# of MD
	Subjects (%)	Subjects (%)	Subjects (%)	Subjects (%)
	(Total #) ^c	(Total #) ^c	(Total #) ^c	(Total #) ^c
Demographics	11 (92%)	10 (83%)	9 (75%)	12 (100%)
	12	13	9	16
Plan	4 (33%)	11 (92%)	4 (33%)	11 (92%)
	9	40	10	25
Tests	1 (08%)	12 (100%)	1 (08%)	12 (100%)
	2	70	2	79
Abdominal	12 (100%)	12 (100%)	10 (83%)	12 (100%)
Pain	21	26	21	20
Tender	1 (08%)	5 (42%)	2 (17%)	7 (58%)
	1	5	2	7
Vital Signs	2 (17%)	1 (08%)	6 (50%)	1 (08%)
	3	1	6	1
Fever	4 (33%)	5 (42%)	7 (58%)	4 (33%)
	4	9	7	4
Tachycardia	1 (08%)	4 (33%)	6 (50%)	1 (08%)
	1	6	6	1

^a CASE C1 = Non-highlighted pancreatitis case

^b CASE C1HL = Highlighted pancreatitis case

^c Total number of concepts included in the case

Appendix O: The Main Effect Between and Within Physicians and Nurses

Effect	F	df	Significance
(Between Subjects)	9.414	(7, 40)	< .001
Occupation Effect			
(Within Subjects)	1.053	(7, 40)	.411
Highlighting Effect			
(Within Subjects)	1.993	(7, 40)	.080
Highlighting and Occupation Interaction Effect			

Appendix P: Conceptual Differences between Nurses and Physicians in Gastroenteritis

Cases (Highlighted and Non-highlighted)

Concept	Case C2 ^a	Case C2 ^a	Case C2HL ^b	Case C2HL ^b
	# of RN	# of MD	# of RN	# of MD
	Subjects (%)	Subjects (%)	Subjects (%)	Subjects (%)
	(Total #) ^c	(Total #) ^c	(Total #) ^c	(Total #) ^c
Tests	4 (33%)	12 (100%)	3 (25%)	12 (100%)
	8	55	10	74
Diarrhea	11 (92%)	12 (100%)	8 (67%)	10 (83%)
	22	27	22	17
Vomiting	9 (75%)	12 (100%)	10 (83%)	11 (92%)
	18	25	16	20
Demographics	11 (92%)	12 (100%)	12 (100%)	10 (83%)
	11	15	12	15
Plan	4 (33%)	11 (92%)	3 (25%)	10 (83%)
	7	24	6	31
Nausea	6 (50%)	10 (83%)	4 (33%)	6 (50%)
	6	13	4	8
Fever	7 (58%)	10 (83%)	4 (33%)	9 (75%)
	7	13	5	15
Hematochezia	6 (50%)	9 (75%)	5 (42%)	9 (75%)
	8	10	7	13
Colon Cancer	4 (33%)	8 (67%)	6 (50%)	6 (50%)
	12	24	15	18
Infection	0 (00%)	8 (67%)	1 (8%)	6 (50%)
	0	16	2	17
Abdominal	8 (67%)	7 (58%)	9 (75%)	8 (67%)
Pain	12	12	14	19

Concept	Case C2 ^a	Case C2 ^a	Case C2HL ^b	Case C2HL ^b
	# of RN	# of MD	# of RN	# of MD
	Subjects (%)	Subjects (%)	Subjects (%)	Subjects (%)
	(Total #) ^c	(Total #) ^c	(Total #) ^c	(Total #) ^c
Medications	8 (67%)	7 (58%)	4 (33%)	7 (58%)
	8	10	4	16
Tender	1 (8%)	7 (58%)	2 (17%)	7 (58%)
	1	7	2	8
Dehydrated	0 (0%)	7 (58%)	3 (25%)	4 (33%)
	0	7	4	4
Mitral Valve	4 (33%)	6 (50%)	1 (8%)	4 (33%)
Prolapse	4	11	1	7
Alcohol	0 (00%)	6 (50%)	2 (17%)	2 (17%)
	0	7	2	2
Precipitators	0 (00%)	6 (50%)	0 (00%)	8 (67%)
	0	13	0	14
IV	12 (100%)	2 (17%)	10 (83%)	2 (17%)
	18	2	15	2
Clear Liquids	7 (58%)	2 (17%)	6 (50%)	2 (17%)
	8	2	6	2
Vital Signs	7 (58%)	2 (17%)	6 (50%)	0 (00%)
	8	2	7	0
Allergy Sulfa	6 (50%)	4 (33%)	2 (17%)	6 (50%)
	6	4	2	6
Mucous	1 (8%)	3 (25%)	3 (25%)	6 (50%)
	1	3	3	6
Guaiac Positive	2 (17%)	5 (42%)	6 (50%)	4 (33%)
	2	6	6	4

Concept	Case C2 ^a	Case C2 ^a	Case C2HL ^b	Case C2HL ^b
	# of RN	# of MD	# of RN	# of MD
	Subjects (%)	Subjects (%)	Subjects (%)	Subjects (%)
	(Total #) ^c	(Total #) ^c	(Total #) ^c	(Total #) ^c
Temperature	3 (25%)	4 (33%)	6 (50%)	4 (33%)
	4	5	6	4

^a CASE C2 = Non-highlighted gastroenteritis case

^b CASE C2HL = Highlighted gastroenteritis case

^c Total number of concepts included in the case

Appendix Q: RN Conceptual Differences between Non-highlighted and Highlighted

Pancreatitis Cases

Concept	Case C1 ^a	Case C1HL ^b
	# of RN Subjects (%) (Total #) ^c	# of RN Subjects (%) (Total #) ^c
Abdominal Pain	12 (100%) 20	10 (83%) 21
Can't Eat	7 (58%) 9	6 (50%) 8
Demographics	11 (92%) 12	9 (75%) 9
Alcohol	6 (50%) 12	4 (33%) 7
IV	11 (92%) 14	10 (83%) 13
Medications	10 (83%) 21	9 (75%) 21
Morphine	8 (67%) 9	5 (42%) 6
Tobacco	6 (50%) 11	5 (42%) 11
Vomiting	9 (75%) 14	9 (75%) 15
Fever	4 (33%) 4	7 (58%) 7
Gastritis	4 (33%) 5	6 (50%) 8
Tachycardia	1 (08%) 1	6 (50%) 6

Concept	Case C1 ^a	Case C1HL ^b
	# of RN Subjects (%)	# of RN Subjects (%)
	(Total #) ^c	(Total #) ^c
Vital Signs	2 (17%)	7 (58%)
	3	7

^a CASE C1 = Non-highlighted pancreatitis case

^b CASE C1HL = Highlighted pancreatitis case

^c Total number of concepts included in the case

Appendix R: Conceptual Differences between Gastroenteritis Non-highlighted and

Highlighted

Concept	Case C2 ^a	Case C21HL ^b
	# of RN Subjects (%) (Total #) ^c	# of RN Subjects (%) (Total #) ^c
Abdominal Pain	8 (67%) 12	9 (75%) 14
Allergy Sulfa	6 (50%) 6	2 (17%) 2
Clear Liquids	7 (58%) 8	6 (50%) 5
Demographics	11 (92%) 11	12 (100%) 11
Diarrhea	11 (92%) 22	8 (67%) 22
Fever	7 (58%) 7	4 (33%) 5
Hematochezia	6 (50%) 8	5 (42%) 7
IV	12 (100%) 18	10 (83%) 15
Nausea	6 (50%) 6	4 (33%) 4
Vital Signs	7 (58%) 8	6 (50%) 7
Vomiting	9 (75%) 18	10 (83%) 16
Temperature	3 (25%) 4	6 (50%) 6

Concept	Case C2 ^a	Case C21HL ^b
	# of RN Subjects (%)	# of RN Subjects (%)
	(Total #) ^c	(Total #) ^c
Colon Cancer	4 (33%)	6 (50%)
	12	15

^a CASE C2 = Non-highlighted gastroenteritis case

^b CASE C2HL = Highlighted gastroenteritis case

^c Total number of concepts included in the case

Appendix S: Conceptual Differences between Pancreatitis Non-highlighted and
Highlighted Cases

Concept	Case C1 ^a	Case C1HL ^b
	# of MD Subjects (%) (Total #) ^c	# of MD Subjects (%) (Total #) ^c
Abdominal Pain	12 (100%) 26	10 (83%) 20
Demographics	12 (100%) 19	12 (100%) 16
Alcohol	9 (75%) 16	11 (92%) 22
Gastritis	9 (75%) 17	10 (83%) 17
Medications	7 (58%) 18	10 (83%) 27
Nausea	9 (75%) 13	8 (67%) 12
Pancreatitis	9 (75%) 20	10 (83%) 18
Plan	10 (83%) 40	11 (92%) 25
Tender	5 (42%) 5	7 (58%) 7
Tests	12 (100%) 70	12 (100%) 79
Tobacco	6 (50%) 9	7 (58%) 8
Vomiting	10 (83%) 21	8 (67%) 13

Concept	Case C1 ^a	Case C1HL ^b
	# of MD Subjects (%)	# of MD Subjects (%)
	(Total #) ^c	(Total #) ^c
Tremors	7 (58%)	2 (17%)
	9	4

^a CASE C1 = Non-highlighted pancreatitis case

^b CASE C1HL = Highlighted pancreatitis case

^c Total number of concepts included in the case

Appendix T: Conceptual Differences Between Gastroenteritis Non-highlighted and
Highlighted Cases

Concept	Case C2 ^a	Case C2HL ^b
	# of MD Subjects (%) (Total #) ^c	# of MD Subjects (%) (Total #) ^c
Abdominal Pain	7 (58%) 12	8 (67%) 19
Colon Cancer	8 (67%) 24	6 (50%) 18
Demographics	12 (100%) 15	10 (83%) 15
Diarrhea	12 (100%) 27	10 (83%) 17
Fever	10 (83%) 13	9 (75%) 15
Hematochezia	9 (75%) 10	9 (75%) 13
Infection	8 (67%) 16	6 (50%) 17
Medications	7 (58%) 10	7 (58%) 16
Nausea	10 (83%) 13	6 (50%) 7
Plan	11 (92%) 24	10 (83%) 31
Precipitators	6 (50%) 13	8 (67%) 15
Tender	7 (58%) 7	7 (58%) 7

Concept	Case C2 ^a	Case C2HL ^b
	# of MD Subjects (%) (Total #) ^c	# of MD Subjects (%) (Total #) ^c
Tests	12 (100%) 55	12 (100%) 74
Vomiting	12 (100%) 24	11 (92%) 20
Dehydrated	7 (58%) 7	4 (33%) 4
Alcohol	6 (50%) 7	2 (17%) 2
Mitral Valve Prolapse	6 (50%) 11	4 (33%) 7
Allergy	4 (33%) 4	6 (50%) 6
Mucous	3 (25%) 3	6 (50%) 6

^a CASE C2 = Non-highlighted gastroenteritis case

^b CASE C2HL = Highlighted gastroenteritis case

^c Total number of concepts included in the case

Appendix U: Curriculum Vita

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PUBLICATIONS:

Articles:

Johnson, T.R., Zhang, J., Tang, Z., **Johnson, C.**, Turley, JP. (2003). Assessing informatics students' satisfaction with a web-based courseware system. Accepted for publication in the International Journal of Medical Informatics.

Traverso, G., Diehl, F., Hurst, R., Shuber, A., Whitney, D., **Johnson, C.**, Levin, B., Kinzler, K., Vogelstein, B. (2003). Multi-color in vitro translation. *Nature Biotechnology* 21, 1093 - 1097.

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GRANTS/FELLOWSHIPS RECEIVED:

- 2001 – 2003 PI: National Library of Medicine F38 Applied Informatics Fellowship
 “Applying Usability to a Knowledge-Based System”
 \$135,707
- 1999 - 2002 Texas Higher Education Coordinating Board Advanced Research
 Program/Advanced Technology Program
 "Redesign of a Genetics Tracking Program to Improve Ease and Use and
 Reduce Errors"
 \$225,000

PROFESSIONAL MEMBERSHIPS:

American Medical Informatics Association
 Human Factors and Ergonomics Society
 Cognitive Science Society

PROFESSIONAL SERVICE:

- 1999 - 2000 Steering Committee Member, Texas Cancer Council, Action Plan on
 Colorectal Cancer for the State of Texas, Houston, Texas

HONORS AND AWARDS:

- 2000 Merit Scholarship Recipient from the Association for Women In Science
 Gulf Coast Chapter
 Houston, Texas
- 1999 Scholarship Recipient from the Committee on the Status of Women
 The University of Texas - Houston Health Science Center
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