Understanding Intensive Care Unit Clinical Communication Using Knowledge Representation

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By

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The undersigned, appointed by the dean of the Graduate School,

have examined the Dissertation entitled

UNDERSTANDING INTENSIVE CARE UNIT CLINICAL COMMUNICATION

USING KNOWLEDGE REPRESENTATION

Presented by Saif Khairat

A candidate for the degree of

Doctor of Philosophy

And hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Stevan Whitt

DEDICATION

To my parents who support me since the day I stepped a foot to this world. If I wrote a book expressing my gratitude, appreciation and admiration to my parents, I don't think I will have fulfilled a fraction of what they deserve. I dedicate my humble success to them and thank them for raising me the way I am today. I am truly blessed to be your son and I hope with the end of my student journey, I have not let you down.

To my sister, Salma Khairat, for the tremendous support she showed me, for the patience she exercised with me especially during difficult times, and for her unconditional love day in and day out.

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ABSTRACT

According to the Institute of Medicine (IOM) report in 1999, every year between 44,000 and 98,000 patients face serious injuries or death due to medical errors. Clinical Communication failures are considered the leading cause of those medical errors [1]. We believe that minimizing communication problems among clinical team members can increase patient safety and improve health care services. Our main focus is, through knowledge representation, to develop an understanding of the communication framework within health care. This will serve as the foundation to our long term goal of building an ontology-driven educational tool that will be used to educate clinicians about miscommunication issues and as a means to improve it.

In this research, we focus on communication patterns within the Intensive Care Unit (ICU) setting. The reason behind our choice is the fatal effect of medical errors on critical care patients. With minimal time to act and high precision required, the occurrence of communication errors is more probable and the negative impact on the clinical workflow is greater. From that perspective, we designed a pilot study through reviewing literature and preliminary observations at the ICU. This research aims at building an exhaustive representation of the communication framework to be implemented in error reporting systems through an ontological approach. The ultimate goal of our research is to improve clinical communication knowledge by developing a framework that represents the communication process in the ICU.

Key words: Intensive Care Unit, Clinical Communication, Patient Safety, Knowledge Representation, Medical Errors.

CHAPTER 1 - INTRODUCTION

Without a doubt patient safety, which is the prevention of medical errors that lead to adverse events, has been the utmost focus of many clinicians and clinical researchers. It is evident that patient safety levels are strongly tied with the frequency of medical errors. The impact of medical errors on patients varies from near misses to injuries or loss of lives. The Institute of Medicine (IOM)[1], the Harvard Medical Practice Study [2], the Quality in Australian Health Care Study [3], all state that inefficient communication is a significant factor in the occurrence of medical errors. By deduction, the quality of clinical communication is an essential factor towards error-free practices and safer patients. This research aims to introduce a novel approach to further understand clinical communication by: (1) studying previously used methods, (2) developing a hybrid research instrument, and (3) utilizing informatics to collect, organize and analyze our clinical communication observations data repository. In this hypothesis-driven research, we hypothesize that there is a relationship between the communication skills of a lead physician and the level of understanding among the clinical team, through analyzing Human-Human and Human-Computer interactions (HCI).

Medical Errors in health care are estimated to cost more than $5 million per year in a large teaching hospital [4]. The causes behind those errors are various; however, clinical communication is listed as the main cause of medical mishaps [3, 5, 6]. According to a report by the Institute of Medicine (IOM) [1], preventable health care-related injuries cost the economy from $17 to $29 billion annually, of which half are health care costs. On the societal level, the massive cost of medical errors affects the health care industry as well as the U.S. economy at large. In 2006, the IOM stated that at least 1.5 million preventable adverse drug events occur annually in the United States as a result of medication errors [7]. This remarkably high cost of injuries has a significant impact on individual's wellbeing as well as the society. By understanding the causes of medical errors and efficiently evaluating possible solutions, preventable medical errors can be minimized and hence, improve patient safety and reduce health care costs.

In this research, we define communication as the exchange of ideas, messages or knowledge between two or more entities through oral and written forms, or signals. In health care, professionals carry dialogues using traceable mediums such as Electronic Medical Record (EMR) systems, paper chart or emails; and untraceable channels like face-to-face discussions. Communication problems arise when the instructions are incomplete or incoherent and therefore, incorrect tasks are performed which lead to medical errors. However, communication failures, whether traceable or untraceable, are hard to catch.

In 2003, a research was conducted to observe communication patterns between physicians, nurses and pharmacists, also known as clinical-to-clinical communication. Results suggested that through the use of technology and EMR to enhance communication better communication can be reached [8]. The use of technology to reduce medical errors is necessary however, the need to understand how and why medical errors occur as a result of miscommunication is essential. In another study carried out in Denver, some of the causes behind miscommunication were attributed to the complexity of health care structure and differences in education and training among health professionals [9]. Those results provide the necessary background for diagnosing the causes behind miscommunication between health professionals.

This research refers to patient safety as the concept of patients receiving care services free from accidental injuries. The term medical errors are defined as preventable adverse events that can result in near misses, injuries, or casualties. Furthermore, we define clinical communication as the exchange of ideas, messages or knowledge between two or more entities through verbal, non-verbal, written, and visual forms where entities represent clinicians or technology aided-devices components. Since health care includes communication through clinicians and technology, our definition uses the term "entities" to refer to both clinicians and technology aided-devices.

Clinical communication occurs through four channels as defined above. Verbal communication is the use of words, languages, sounds, and speaking to convey a certain set of messages. Non-verbal communication focuses on physical ways to communicate including body posture, facial expressions, and gestures. Written communication forms refer to various documented message exchanges such as handwritten notes and computerized or typed notes. Finally, visual forms of communication represent information exchange through visual aid instruments such as X-rays, charts, and graphs in a clinical setting.

Furthermore, the strength of this research is present in the science behind the theoretical framework used. This research utilizes qualitative approaches such as interviews and observations to understand and explain social and cultural phenomena in health care. Different qualitative research methods have been used in different disciplines such as action research in education [10], case research in marketing [11], ethnography in health care [12], and grounded theory in engineering [13]. We believe that the method with the ability to develop a theory from data repository that was systematically gathered and analyzed should be the method of choice. The unique proposition that there should be continuous relationship between data collection and analysis makes grounded theory the most effective research method for this research [14]. The major premise of grounded theory is that to produce accurate and useful results as well as its excellent ability to develop process-oriented descriptions and explanations of a phenomenon [14]. For these reasons, grounded theory scientifically fits well with our research problem.

The ultimate of goal of our research is to build a clinical communication ontology which represents a conceptual representation of the communication framework at the ICU. The choice of using ontology is because ontologies handle information between general categories and specific cases by defining relationships and hierarchies. This facilitates the description and mapping of information from general domains to the particular tasks, which assists knowledge representation. An important feature of ontology processing is its visualization characteristics. Relations between concepts can be visualized to facilitate the educational mission aimed at various clinicians. Such ontology can be used in medical error reporting systems in order to enhance the quality of medical error reported incidents.

CHAPTER 2 - LITERATURE REVIEW

2.1 Search Strategy

The first step towards further understanding the clinical communication process is to search, gather, and analyze past and current related literature. In order to ensure conducting a thorough search, our search strategy was to search through literature databases and Google search engine for articles using the keywords mentioned below. The literature database that returned most relevant search was Ovid Medline database, and so, most of the retrieved literature came from Ovid or Google search.

Search terms used included: intensive care units, emergency rooms, operating rooms, aviation, air control, communication, clinical communication, medical errors, medication errors, sentinel events, latent errors, active errors, epidemiology of errors, near miss, patient safety, knowledge representation, human-human interaction, human-computer interaction, ergonomics, human processes, ontology, taxonomy.

The literature search was not restricted to a certain number of years because communication is an old research field and many significant theoretical models and interventions were developed in the middle of last century. The search was not limited to journal publications; rather, it included all sources of literature such as books, conference proceedings, journal papers, and research abstracts. All literature reviews were published in English, and no other languages were included in the search due to the absence of scientific translator.

Since this research focuses on clinical communication at the ICU, the search methodology followed a top-down approach, which started at high level descriptive keywords and then narrowed down the search by using more definitive terms. Table 1 shows the search strategy used when searching Ovid database. Two broad keywords where used to retrieve domain-related articles such as literature in ICU and medical errors. Then, three specific keywords were used in the search to yield literature of focus in “clinical communication”, “knowledge representation”, and “human-computer interaction”. The search results to this point retrieved 128495 publications, so more sophisticated search strategy was used to extract literature of strong degree of relevance. A series of “AND” operations were executed to retrieve articles that include one or more keywords. In table 1, number 6 shows that 40 publications were retrieved as a result for searching for “medical errors” and “clinical communication”. Then, another “AND” operation was executed on the results from the previous search and the term “clinical communication”, 6 publications were returned. Similarly, the same procedure was repeated with the terms “intensive care unit” and “medical errors”, the summation of both searches was 126961; however, after executing the “AND” operation the search results returned only 719 publications. Those results were further searched to retrieve literature with a focus on clinical communication; the results returned only 6 papers. Furthermore, since one of the focuses of this research is human-computer interaction, an “AND” operation was executed on the terms “intensive care unit” and “human-computer interaction” to gather literature that conducted HCI work in ICUs. Finally, in an attempt to understand how much knowledge representation efforts have been done with regards to medical errors, another “AND” execution was done to yield such literature.

Table 1 Literature search results from Ovid Databases

Number	Search Statement	Results
1	intensive care unit.af.	112685
2	medical errors.af.	14006
3	clinical communication.af.	492
4	knowledge representation.af.	787
5	human-computer interaction.af.	525
6	2 and 3	40
7	1 and 2	719
8	3 and 7	6
9	1 and 5	20
10	2 and 4	4
11	1 and 6	6

Through this search strategy, the large number of related literature was condensed to literature of strong relevance. This facilitated the analysis phase because it eliminated many unrelated literature and also, the strategy helped define and classify each pool of literature which facilitated the process of literature review.

2.2 Specific Aims

The ultimate goal of this proposal is to improve clinical communication by developing an inclusive framework that identifies the strengths and limitations of the communication process. This research focuses primarily on the activity of the Attending Physician (AP) among the team since LPs are on the top of the hierarchical structure of the clinical team. Amongst other duties, the Lead Physician delegates' tasks to other team members, sets daily goals, and acts as a nucleus to most communication events.

We hypothesize that there is a relationship between the communication skills of a lead physician and the level of understanding among the clinical team, through analyzing Human-Human and Human-Computer interactions. The communication skills of the Attending Physician that are of focus in this research are the use of feedback, the purpose behind communication, and the response of the Attending Physician to interruptions by humans and technology. Also, the analysis of the H-H and H-C interactions include two levels of analysis: (1) the type of interactions, (2) the frequency of observed interactions. We aim at identifying the types of interactions and their impact by measuring their frequencies and the response of the Attending Physician to their occurrences.

Specific Aim #1. To test the hypotheses that the use human-human and human-computer interactions, during ICU patient rounds, can further improve the team member's awareness of daily goals by comparing the frequency and types of each interaction against the awareness questions in the survey.

Specific Aim #2. To test the hypothesis that the use of Attending Physician to feedback, verbal and nonverbal, has an effect on the satisfaction levels of the team, by analyzing the use of feedback from observation against the response to survey questions.

Specific Aim #3. To test the hypothesis that communication tasks performed by the Attending Physician can facilitate task awareness among team members by comparing the frequency of each Attending Physician task field against the effectiveness question in the survey.

Specific Aim #4. To test the hypothesis that communication outcomes vary on weekdays as compared to weekend days by comparing the frequency of communication variables, and by studying changes in communication patterns to Attending Physician interactions with other members and with technology. Also, we are interested to examine the effect of time on communication behaviors; in other words, at the beginning of the rotation there we suspect to observe more teaching and instructions given by the Attending Physician as the team gets acquainted. Therefore, we aim at examining any patterns in frequencies among communication variables between week 1 and week 2 of the Attending Physician rotation period.

A primary data collection and transcription protocol has been developed to avoid collecting irrelevant data and to ensure high data validity and reliability. Through data acquisition, we expect to yield valuable data that adds more meaningful knowledge to our data repository. This knowledge will assist in the development of clinical communication ontology through revealing key communication factors that positively or negatively impact team communication. Moreover, by building and analyzing the repository of clinical communication data, we aim at further delineating the clinical communication model we have proposed through identifying effective communication factors [15]. The communication model provides a clear breakdown of communication factors however; further efforts are needed to validate the model. Previous work in this field provides valuable knowledge of raw categories such as cognitive use and language barriers, however to our knowledge, no data collection tool has been proposed, which prevents new researchers from continuing previous efforts. Therefore, the objective of this study is to develop a validated ICU data collection tool that can be shared, used, or modified by other researchers to enhance clinical communication.

2.2.1 Specific aims analysis

Despite the significance of clinical communication in research publications, there is a need to understand the theoretical motive behind the focus of this study. As a part of cognitive science, the distributed cognition theory, one of the most relevant theories to communication, seeks to further understand the structure of cognitive systems by focusing on individuals and organizations. The theory aims at rebuilding the cognitive system from the outside in, by looking at the social and materialistic settings and linking that with the knowledge inside individuals [16]. Following this scientific rational, the first specific aim was designed to study the external settings in which communication occurs specifically, by studying the interactions and interruptions caused by technology and humans. Then, the 2 and 3 specific aims study the use of tacit knowledge an LP acquires to communicate with the team, which can be measured through feedback and tasks performed by the LP. Moreover, the findings of ICU researches state that patients admitted to the ICU on weekends are at higher risk of death or will experience more complications than patients admitted on weekdays [17, 18]. We suspect that a contributing factor to those research findings is the variance in communication intensity and details on weekend days compared to weekend. Therefore, we intend to examine relationships and patterns between the data collected on weekdays and the corresponding data from weekends.

2.3 Medical Errors and Human Factors and Ergonomics

The field of human factors engineering, also called ergonomics, is the discipline whose goal is to improve the relationship between humans and systems [19]. In 1999, the Institute Of Medicine (IOM) released a report that documented the effect of the current health system design on medical errors, namely wrong-site surgeries and transplant errors [20]. The field of human factors/ergonomics (HF/E) proposes new methodologies to improve the current state of health systems and hence, introduces new interventions to prevent future tragedies. The national cost of medical errors is more than $17 billion and has been estimated to be as high as $29 billion. Moreover, a study reports that from 182 patients who died in 12 different hospitals, 14% were reported to be preventable and had resulted in inadequate diagnosis or treatment [21]. Therefore, there is a necessity to study and improve the current system limitations.

Medical errors occur primarily due to the interaction between humans and certain sub-components of the system or the system as a whole. Therefore, there is a need to focus on establishing the potential and identifying the consequences of errors before the system goes live. In other words, during the development and testing phase of the system, a comprehensive study that identifies potential errors and their magnitude in the system should be utilized and assessed. Researchers in the human factors field generally focus on human machine interface, this includes human behavior, abilities, limitations, and use this knowledge to design and develop a system that is safe and effective for human use.

2.3.1 How to define error?

In order to tackle medical errors there needs to be an understanding of what constitutes an error. Therefore, we need a structured definition of error that can define the scale and magnitude of a particular error. Error has been defined as a failure to perform an intended action that was correct given the circumstances [22]. This definition can be further broken down to distinguish between latent and active errors. Active errors results in immediate effects while latent errors may result in adverse consequences that can be dormant in the system for a given time. Also, the difference between mistakes and slips are important to study. Slips are errors which result from certain failure in the execution of a set of actions; mistakes can be defined as failures in the inferences made to achieve a certain aim [23]. By categorizing the various types of errors, it is easier to study and eliminate threats from the system. Also, in order to analyze the medical error problem from human factor perspective, there has to be a comprehensive classification of the types of errors and the root-cause effect.

2.3.2 Current systems limitations

Table1 shows two main categories that directly result in errors and problems within those categories can resolve many limitations in today's systems. The first category relates to assumptions, when developing the architecture of a system, including workflow and technologies used, administrators and managers sometimes oversee some factors during early the planning and design of systems. One of these factors is the need to correctly match the system to meet the number of employees, their skills and capabilities, and the environment. In many cases, errors occur because of the inability of users to match between what goes on in reality and what the system is designed to do which is resolved by users through workarounds, a bypass of problem in the system, to reach their goal. Among other interventions is to have a backup plan in case of any technological failures or changes. During technology problems, organizations cannot afford to waste time and resources until the problem is fixed. For example, if the internal server of the organization crashes or fails to operate there needs to be a backup server that will automatically activate to resume action. Therefore, when designed, systems should be prepared to handle expected and unexpected scenarios.

Table 2 From Ergonomics and the quality movement. [23]

Tenets of Ergonomics/Human Factors	
Assumptions	1. Errors and stress arise when task demands are mismatched to human capabilities. 2. In any complex system, start with human needs and system needs and allocate functions to meet these needs. 3. Honor thy user: use measurements and models to provide the detailed technical understanding of how people interact with systems. 4. Changing the system to fit the operator is usually preferable to changing the operator to fit the system. At least develop personnel criteria and training systems in parallel with equipment, environment, and interface. 5. Design for a range of operators rather than an average; accommodate those beyond the design range by custom modifications to equipment. 6. Operators are typically trying to do a good job within the limitations of their equipment, environment, instructions, and interfaces. When errors occur, look beyond the operator for root causes.
Interventions	1. Prepare well for any technical change, especially at the organizational level. 2. Involve operators throughout the change process, even those in identical jobs and on other shifts. 3. Use teams comprising operators, managers, and human factors engineers (at least) to implement the change process.

2.3.3 The need to utilize human factors to minimize errors

The motivation behind those efforts is to minimize medical errors, which according to results from IOM are the fourth largest killer of Americans [20]. Among those limitations are medical devices. For example, patient-controlled analgesia pumps were identified to have the following errors: (1) failure to remove shipping insert, (2) drug concentration misprogramming, and (3) improper installation of accessories [24]. Those malfunctions in an important devices increase the chances of medical errors occurring. This is why the debugging phase of any medical product is the utmost important step in the whole system engineering process.

Device are not the only cause of errors, human also play an important role in this process. An area of interest in human factors is clinical judgment. Incorrect judgment directly results in medical errors. A study suggests that the level of diagnostic accuracy increases with experience [25]. The reason behind that is the positive linear relationship between expertise level and case recall, in other words, it is easier for clinicians to remember a case if there is a trend or pattern of occurrence. So, what is the concluding sentence that establishes the need to utilize human factors to minimize errors?

2.3.4 Human factors approaches to error analysis

Error analysis focuses on studying the kind and quantity of errors that occur. For this research, error analysis can be defined as the process to evaluate the total errors that occur in a system. Human factors approaches have proposed many error analysis models such as Management Oversight and Risk Tree analysis (MORT), fault tree analysis, and many others. However, the most common methodology among researchers remains to be

Root Cause Analysis (RCA). Basically, RCA is a set of techniques that are used in problem solving methods, it aims at identify the main cause of problems in a given scenario or event. By 2008, more than 7000 RCAs have been performed at the VA and nearly 4100 submitted to state health departments and health care systems nationwide [26]. In a study at the VA, results of using RCA showed a shift in the root causes identified and problems were attributed to factors such as communication and policies [27].

Therefore, it is evident that RCA is one of the most suitable methodologies used to minimize medical errors in health care. The reason behind that is by using RCA approach on current systems, we can develop an understanding of leading factors towards errors. This understanding can then assist researchers build safer systems in the future that can avoid and prevent errors that used to occur in the past. Moreover, through RCA there is increased ability to predict and forecast errors. This can be a great source of comfort for clinicians since the system can generate alerts and reminders that predict the occurrence of errors. Furthermore, RCA has been used previously in health care and has proved its validity and success in identifying problems and suggesting solutions. The use of root cause analysis has been used to identify near misses in the following fields: cardiovascular nursing [28], drug events in a tertiary referral hospital [29], prenatal nursing [30], information technology (IT) failures in health care systems [31], and veterans [27].

Another error analysis method that can be implemented in health care is Fault Tree Analysis (FTA). In a Medical Emergency Services (MES) study, FTA methods were used to tackle the problem of inappropriate utilization. FTA analyzes the current state of the system using Boolean logic to combine a set of sub components together [32]. FTA analysis was applied to the data collected to calculate the reliability of the various components in the system in order to understand where the defect occurs. Results suggested that the component with the least reliability rate was “patient recognized need for ambulance” with only 66% reliability. Therefore, in order to increase the overall reliability of the system, the event of predicting patient’s need for an ambulance needs to be remodeled.

2.3.5 Analysis approaches

The analysis methodology to be used in solving problems is important however, the way to implement the analysis method is what ensures better results. Therefore, in order to yield the best results out of using error analysis approach in health care systems, there has to be a well-constructed protocol that can govern the analysis process. It is necessary to stress on the importance of selecting the right people for the investigation team. The team should include domain experts who can verify the errors and approve the proposed solutions. In the beginning, there must be a clear definition of the current problem in the system and based on the problem, the correct data needs to be collected. Data collection requires the use of accurate instruments that guarantee validity and variability of the data. The data collection phase is the most important among all phases due to the importance of data when it comes to analyzing the errors and proposing a solution. Based on the data, corrective actions that are within the organization’s control should be identified. The proposed solutions should not limit the system from reaching the original goals and objectives put forth by the organization. The next step is to implement the recommendations based of the error analysis and then, observe and evaluate the overall efficiency of these solutions to ensure effectiveness of the system.

2.3.6 Beyond Errors to Interventions

In the previous section, we discussed way to detect and fix and error however, preventing an error is better than diagnosis. This section explores ways of minimizing the chances of error occurring. In order to stop an error from happening there needs to be an understanding of the leading factors that cause this error. In most cases, the error has to occur in order to back track and analyze what happened. No system is free of errors or bugs however; the number of errors can be reduced to the bare minimum through removal of incorrect assumptions and using correct interventions. This section focuses on possible general solutions that can utilize human factors to minimize medical errors through prevention rather than fixation.

Errors are usually caused due to a problem with the performance, such as quality, or humans, such as productivity, involved in the process. While human factors include process that focuses on increasing the level of quality; those methodologies were developed a few decades ago and the complexity of systems nowadays requires more research to come up with an effective approach to improve quality and efficiency. Among essential interventions of errors are system approaches, allocation of resources, and include user needs and capabilities.

Poor system designs results in an ineffective human-computer interaction which then creates errors. Therefore, when designing a system the ultimate goal should be specified from the beginning, for example, in health care clinicians are the primary users of computer systems. An example of a successful human centered application is the recently design computer system that used graphical displays instead of text to monitor the daily care of patients. This system eliminated the option of nurses entering data and thus, fewer errors in dosages and recording of patients' name. Therefore, there is a need to build human-centered applications that focus on user trends and their knowledge of the system. By doing so, a system that is reliable and serves users' needs and requests can be developed, implemented, and used by users. Moreover, there needs to be training and coaching sessions to the system periodically in order to get the staff familiar with the tools.

Building a human centered tool must include in its planning customers using the tool, in health care those are the patients. By studying and understanding the usability level of patients better tools can be developed that provide better care. At Georgia Institute of Technology experts found that many patients sing the blood-glucose monitors at home were using them improperly. After studying the design of the product, it was found that the three-step blood glucose monitor require patients to conduct 52 sub steps, which naturally results in patients making errors. When a better design was proposed by researchers the correct use of the meter improved a lot [33]. By correctly designing a tool for patient use, errors can be reduced to a minimal level and health organizations can yield better medical results which will in return increase the overall efficiency of the system.

The other important factor is how to efficiently use the resources available to establish a human centered system that is productive and efficient. We have learned in various cases that one of the driving costs of an organization is the way workflow is designed. Through calculating waiting time in queue, the capacity needed to meet customer expectation, and the human power and materials needed to meet the demand; the efficiency of the organization can maximize. As for technology, there are inconsistencies in the role of technologies in health care. Some technologies are used by clinicians differently than what they were originally designed to do which created errors. This occurs due to lack of involvement of users during the designing and creation phases. Therefore, a preventive way is to aim for a human-centered application and involve users in the specifications of the tool. That way when the final product goes live, users will receive a product that is up to their expectations and void of their concerns.

Therefore, Medical errors forms serious threat to patients and health care providers and ways to minimize errors have not been fully identified or implemented. In order to minimize errors, there is a need for a complete understanding and a structured definition of errors that can clearly identify problems. The area of human factors and ergonomics research has provided much work that focuses on system safety and design solutions for complex systems. Therefore, results from ergonomics research needs to be utilized in system design and development to reduce medical errors, increase effectiveness and overall efficiency. However, the implementation of these solutions is not enough to reach the level of quality users expect, this is why prevention is vital. Through prevention, the cost of fixing errors will decrease, and the overall utilization and allocation of resources in the organization will reach maximum levels. To conclude, the field of ergonomics provides much assistance to organizations in dealing with their medical errors and researches from the past shows the significance of human factors in minimizing medical errors.

2.4 HCI in Clinical Communication

Clinical communication is a multifactorial complex structure that requires the delivery of information accurately, the communication process in health care uses various mediums for communication. Professionals utilize verbal, non-verbal, and technology-aided devices to communicate amongst each other. Human-Human and Human-Computer interactions are present within this process which has resulted in inconsistent accuracy levels to communication based on the utilized communication medium. Table 3 shows the mostly used communication channels in each interaction. It is evident that within each communication channel there are many factors that need to be addressed in order to enhance overall communication levels.

Table 3 Types of clinical communication channels based on type of interaction.

Interactions	**Communication mediums**
Human-Human interactions	○ Verbal ○ Written ○ Body language
Human-Computer interactions	○ Information storage ○ Information retrieval ○ Clinical alerts ○ System messages /errors

In recent years, a new generation of computer systems was introduced to health care; those systems are designed to perform more sophisticated tasks beyond basic information entry and retrieval. Those systems aimed at assisting and improving clinical decisions. Those computer-based systems, such as Clinical Decision Support Systems

(CDSS) and Electronic Medical Records (EMR), have facilitated evidence-based and patient care by reducing serious medication errors [34] and enhancing the delivery of preventive care services[35] [36]. However, about 34% of computer-based systems have shown insignificant progress in clinical practice [36]. One of the major reasons for this inefficiency is, as the use of Health Information Systems (HIS) and Computer Information Systems (CIS) increase, new medical errors are introduced. The types of errors produced by both systems differ for each type; HIS mainly keeps track of administrative issues and CIS concentrates on patient-related data such EMRs. However, many errors from both systems can be related to miscommunication. Therefore, the communication model, proposed in later sections, addresses communication limitations in both HIS and CIS.

A previous study shows that there are two categories of errors that occur during human-computer interactions. The first is errors submitting and retrieving information to and from an information system and secondly, errors in the communication and coordination processes that (CIS) is supposed to support [37]. In order to improve clinical communication, human-computer interaction has to be considered as a major component of the communication process. We believe that CIS should facilitate communication between clinicians, ensure correct clinical data flow and most importantly, improve health care services to the maximum effect.

2.4.1 Review of current HCI methods

In a field with such diversity, the utilization of research methods are numerous and for that reason this research will highlight the most common research methods used in previous HCI efforts. Among the most commonly used research methods are surveys, field study, controlled experiment, and instrument development. Table 4 summarizes results from a study conducted on the intellectual development of HCI research in Management Information systems (MIS), the study focused on understanding what types of methodologies are most popular [38]. The research examined a pool of 378 HCI published papers; the goal was to understand the popularity of available HCI research methods. Findings suggest that the three most utilized methods were controlled lab experiments, surveys, and field studies, followed by field experiment, instrument development, and others. Moreover, results show that the overwhelming majority of research papers used empirical research methods, in other words methods based on observation and experience. Even though many researches used only one methodology in their work, there are an increasing number of publications that utilized two methods in their work.

Table 4 Breakdown of commonly used methodologies among 378 publications.

Research Method	**Number of Papers (total = 337)**	**% from total number of papers**
Controlled lab experiment	134	35.6%
Surveys	96	25.5%
Field studies	47	12.5%
Study type	**Number of papers (total = 378)**	**% from total number of papers**
Empirical	342	90.5%
Non-Empirical	36	9.5%
Number of methods per study	**Number of papers (total = 337)**	**% from total number of papers**
One method	298	88.4%
Two methods	37	10.9%

Moreover, in HCI, research methods can be categorized into three categories: (1) Natural settings, (2) Artificial setting, (3) Environment independent setting [39]. The natural setting category includes methods such as case studies, field studies, and action research. These methods can generate rich data based on the first hand data as well as, the opportunity to collect first hand data increases the reliability of findings. On the contrary, these methods can be time consuming, data collection can be challenging due to scarcity of human resources, and the generalizability of the study maybe questionable. Methods in this category can be used to evaluate new practices, test new theories, or develop hypothesis. Artificial settings tend to include laboratory experiments as its methods, the benefits of using such methodology is the ability to control the variables and also, to replicate trials. Weakness of this category can be shown in the absence of realism and in certain cases the level of generalizability is unknown. This category can be of use in controlled experiments and theory testing researches. Finally, the environment independent setting category includes research methods such as surveys, applied and basic research, and normative writings. These methods are best used to collect data from large samples, product development, and building theories and frameworks. Those methods can be conducted at relatively low costs, reduce sample bias, and provide insight on first hand data. On the contrary, there is a challenge to manipulate variables, and in some cases opinions might influence outcomes which affect the truthiness of research. This research will incorporate the significant findings from previous researches to maximize the yield of our work and hence, reach the ultimate goal of this research which is to improve clinical communication.

2.4.2 HCI in Healthcare

In 2008, the health care industry provided 14 million job opportunities and potentially 3.2 million new jobs by 2018, which makes the health care sector the largest and most diversified industry [40]. Also, health care is one of the few sectors that directly impact the wellbeing of citizens and better health care directly results in a shift in the population health status. The health care structure integrates two core components to provide services and care: human resources and technology. New Information Technologies (IT) serve as means towards advancement however, there are calls for better technology integration. IT in health care can be introduced in two main areas: treatment process and medical records. From that perspective, HCI research methods can be applied in those domains to provide more efficient systems and effective work flow.

In 1999, IOM released a report that documented the effect of the current health system design on medical errors, namely wrong-site surgeries and transplant errors [20]. The field of Human Factors (HF) proposes new methodologies to improve the current state of health systems and hence, introduces new interventions to prevent future tragedies. The national cost of these medical errors is over $17 billion and has been estimated to be as high as $29 billion. Moreover, a study reports that from 182 patients who died in 12 different hospitals, 14% were reported to be preventable and had resulted in inadequate diagnosis or treatment [21]. Therefore, there is a necessity to study and improve the current system limitations.

Medical errors occur due to the interaction between users and certain sub-components of the system or medical devices [24]. Therefore, there is a need to focus on establishing the potential and identifying the consequences of errors before full systems deployment. In other words, during the development and testing phase of the system, a comprehensive study that identifies potential errors and their magnitude in the system should be utilized and assessed. Researchers in the human factors field generally focus on human machine interface, this includes human behavior, abilities, limitations, and use this knowledge to design and develop a system that is safe and effective for human use.

The motivation behind utilizing those efforts in health care is to minimize medical errors, which according to results from IOM are the fourth largest killer of Americans [20]. One of those limitations are medical devices for example, patient-controlled analgesia pumps were identified to have the following errors: (1) failure to remove shipping insert, (2) drug concentration misprogramming, and (3) improper installation of accessories [24]. Those malfunctions in an important devices increase the chances of medical errors occurring. This is why the debugging phase of any medical product is the utmost important step in the whole system engineering process.

Devices are not the only cause of errors; users also play an important role in this process. An area of interest in human factors is clinical judgment. Incorrect judgment directly results in medical errors. A study in Netherlands focusing on clinical cases suggests that the level of diagnostic accuracy increases with user experience [25]. The reason behind that is the positive linear relationship between expertise level and case recall, in other words, it is easier for clinicians to remember a case if there is a trend or pattern of occurrence.

2.5 Research Significance

The impact and cures of inadequate health communication is a core interest in the medical research field. Numerous attempts have examined ways to enhance communication between providers and patients [41-45]; even though this type of communication is of utmost importance, yet, there is another type of communication that is as significant, namely, communication among care givers. Our work focuses on the communication patterns among the Intensive Care Unit (ICU) clinical team.

In health care, communication is considered the backbone of many basic and crucial tasks for instance in education, information dissemination, knowledge exchange, and decision making. Clinical communication has a pivotal role in the information flow cycle; scientific evidence shows that communication errors can cause significant morbidity and mortality rates [46]. For those reasons, strong clinical communication is paramount for better health care outcomes. The following sections discuss human factors and ergonomics, and define clinical communication; introduce the significance of clinical communication, current communication models, and the need for a clinical communication model.

2.5.1 What is Clinical Communication?

Communication is a flexible term with fluctuating boundaries and in order to better define the scope of the communication process in health care there is a need for an accurate description of the term clinical communication. In this research we define communication as the exchange of ideas, messages or knowledge between two or more entities through verbal, non-verbal, written, and visual forms where entities can be individuals or technological components. Since health care includes communication through clinicians and computers and in an attempt to encompass human-computer and human-human interactions, our definition uses the term “entities” to refer to communication among both humans and technology aided-devices. Clinical communication can be categorized into the four categories mentioned in or definition.

Verbal communication is the use of words, languages, sounds, and speaking to convey a certain set of messages. Non-verbal communication focuses on physical ways to communicate such as body language, body posture, facial expressions, and gestures. Written communication forms refer to various documented message exchanges such as handwritten notes and computerized or type notes. Finally, visual forms of communication represent information exchange through imaging tools such as X-rays, charts, and graphs in a clinical setting.

2.5.2 The Significance of Clinical Communication

Medical errors are a national nightmare that everyone, from care givers to patients, is trying to escape from. In 2010, the Office of Inspector General (OIG) at the Department of Health and Human Services reported that each month one out of seven Medicare patients is injured or killed by medical errors [47]. The same report states that medical errors cost $4.4 billion in 2009 taxpayer dollars. The findings of the OIG report affirm the previous reports from the Institute of Medicine (IOM) which state that as many as 98,000 people die each year as a result of preventable errors [1]. This shows that medical errors have higher mortality rates exceeding other causes of deaths such as auto accidents and breast cancer. Furthermore, the IOM reported that preventable health care-related injuries cost the economy from $17 to $29 billion annually, of which half are health care costs. These statistics show that medical errors represent a heavy burden on the economy, and most importantly, the loss of life due to medical errors is definitely an unwanted consequence.

Clinical miscommunication, the failure or incompleteness of message exchange, is the lead cause behind 75% of medical errors and 82% of sentinel events [1, 48]. Similarly, the Harvard Medical Practice study, and the Australian Health Care study show that inefficient communication is a significant factor in the occurrence of medical errors [2, 3]. Therefore, the association between clinical communication and the outcomes of medical errors is evident. The improvement of communication in health care will yield significantly positive results on the quality of care being delivered and also financially, by achieving lower costs and increasing revenue and profit.

2.5.3 The nature of and communication at ICUs

Patients with life threatening conditions are admitted to the ICU and intensive medical interventions are carried out by the clinical team in a fast-paced environment [49]. The multidisciplinary and complex nature of care required in the ICU makes it a setting ripe for the frequent occurrence of medical errors. Annually, more than two million patients are admitted to urban U.S. ICUs, of which approximately 200,000 die each year [50]. Moreover, mortality rates in admitted ICU patients average 10-20% in most hospitals [51]. The overwhelming environment, overloaded clinicians, and critically ill patients provide a major challenge for effective communication to take place. Across shifts for each patient, the ICU team must communicate throughout the course of treatment in order to perform multiple tasks, obtain numerous lab results, make and adjust diagnoses, treat and prevent pain, provide care and support, and treat underlying health conditions [52].

Communication failures are considered the common cause in ICU adverse events, and calls for improved patient safety through better communication have been made[53, 54]. Among the benefits of better communication is the reduction of patient harm, shorter length of stay, higher caregiver satisfaction, and reduced cost [55-59]. Henceforth, we dedicate this research to studying clinical communication factors in various ICUs such as Pulmonary, Burn, and Cardiac.

2.5.4 Communicating via technology

Health care utilizes various communication channels such as verbal, written, and technology-aided communication. The adoption of Clinical Decision Support Systems (CDSS) and Electronic Medical Records (EMR), have facilitated evidence-based care and patient care by reducing serious education errors and enhancing the delivery of preventive care services[34-36]. However, the utilization of these systems has introduced new medical errors to practice.

In a study examining human-computer interactions, two types of errors were identified: (1) errors submitting and retrieving information to and from a computer information system (CIS), (2) errors in the communication and coordination processes that CIS is supposed to support [37].This suggests that in order to introduce overall improvements to clinical communication, human-computer interaction has to be considered as a major component of the communication process. We believe that CIS should facilitate communication between clinicians, ensure correct clinical data flow and most importantly, improve health care services to the maximum effect. Therefore, the aim of this research is to study and analyze the relationship between human-human and human-computer interactions and communication in health care. Through the research methodology proposed in this paper, we aim at developing a knowledge base that can be utilized to develop an ontology-based web application. Through the use of ontology, clinical communication knowledge can be represented in a meaningful way that will assist the progress of further communication research. The web application will serve as an educational tool that explains communication behaviors and patterns. Through increased awareness and education, clinical communication will enhance and similarly, patient safety and satisfaction will maximize.

2.5.5 Communication Models

Over the course of many centuries, humans have realized the necessity of communication in order to accomplish most affairs, if not all. In the past, the nature of communication was relatively straight forward; it included direct communication between people. This can be shown in most communication models such as the models of Shannon, Berlo, and Shamm[60-62]. Those well-constructed models represent the basic methods of communication and do not include new communication mediums. As new means of communication are being introduced, such as technology-aided devices, there is a need for a new communication model that encompasses new innovations. Moreover, these general communication models are not health care oriented and hence, utilizing the models to represent today's clinical communication will result in an abstract view of what occurs in reality. Currently, clinical communication includes two main components that must be addressed: Human-Human (H-H) and Human-Computer (H-C) interactions.

In order to assess the usability of general models in health care, we studied the strengths and limitations of each of the general models then, we measured the relevance of those models against our first clinical communication model [15]. Results showed that there is a gap between the design of previously proposed models and typical communication scenarios. In the next sections are dedicated to describing the different communication models, and their strengths and weaknesses.

What is a communication model?

In my perspective a model is the static visual representation, or metaphor, of an ongoing, dynamic, and interactive process. Communication models attempt to summarize and express what occurs during the interaction of two or more individuals, or entities. A model should define the communicators, communication mediums, and the mechanism behind the flow of information. Moreover, on a philosophical level, the model should express the factors that affect how messages are being transferred and how they are received and interpreted by the receiver. In his book, Mortensen defined communication models as *"a systematic representation of an object or event in idealized and abstract form. Models are somewhat arbitrary by their nature. The act of abstracting eliminates certain details to focus on essential factors. . . . The key to the usefulness of a model is the degree to which it conforms--in point-by-point correspondence--to the underlying determinants of communicative behavior."*[63] This well-written definition highlights that models can be abstract in nature however, their strengths can be in imitating the point-by-point interaction and by identifying the determinants of the behaviors.

Another point of view states that “communication models are merely pictures; they’re even distorting pictures, because they stop or freeze an essentially dynamic interactive or transactive process into a static picture” [63]. This view can be argued since with today’s technology and resources it is feasible to create dynamic or moving pictures to accurately represent this interactive process. However, it is necessary to note the models cannot capture all communication details in one picture; rather, models focus on representing the framework which acts as the foundation for further explorations.

Benefits and limitations of Communication Models

Prior to building models, the question that should be asked is whether science and research will benefit from such a model, what would be the limitations, and how can those limitations be solved. The benefits of building new models can be summarized in understanding three main phases: (1) past, (2) present, (3) future. Among other functionalities, a model should be able to clarify and explain complexities that have occurred in the real world, which helps with the understanding of previous communication events. Second, once the model has been built, the analysis and exploration of a given model will raise questions and will prove thoughts, which will help better understand the challenges in communication. Mortensen stated that a good model is useful when it is able to provide “general perspective and particular vantage points from which to ask questions and to interpret the raw and stuff of observation” [63]. Thirdly, communication models should lead us to new discoveries and innovations since models offer new insights and visions which can build new hypothetical ideas and relationships; this will open the door to future researchers and scientists to further explore this phenomena.

Moving on, the limitations of solely relying on communication models is that models can lead to the oversimplification of ideas and concepts, and as a result can lead to discreet findings that may not be applicable to reality. Some researchers view models as to have little value because models can miss major points of comparison, and a model is always simpler than the actual subject matter which can be viewed as a virtue and a fault in the same time [64, 65]. Also, models can lead to confusion to readers because of how the subject is portrayed in the model and how it is perceived by the readers. For example, the colors attributed to each country on the world map does not mean that each country is that color in reality; rather, the colors were given for distinction purposes. Finally, Kaplan states that even if a model escapes oversimplifications and confusions, still a model is in danger of incompletion, in other words, some models struggle to avoid premature closure and to achieve a state of completion. Some models, because they are abstract, fail to reach the final steps in a cycle which provides an incomplete model. The danger of such models is that when relied upon, researchers and scientist will bypass or overlook the steps that were not mentioned in the model. The next sections will discuss the major general communication models and their strengths and weaknesses.

Shannon's Model of the Communication Process

Shannon's model was proposed in 1949 by Claude Shannon an engineer for the Bell Telephone Company, the model was designed to help engineers find the most efficient way to transmit electrical signals from one location to the another [63]. Shannon's model is considered the most communication model used in low-level communication discussions because it approximates the process of human communication. The concepts of this model provided cornerstone findings for future communication research, the first concept is entropy, or the measurement of uncertainty in a process, in other words the value of information exchanged depends on the probability of the exchange process taking place. Second concept is redundancy, which explains the degree to which any given information is unique within the communication process. Thirdly, the noise factors introduced to a conversation, which can be defined as the amount of information relayed in a conversation that is not related to the original topic of discussion. Finally, channel capacity which indicates how much information can be relayed within a given channel, in other words, how much can be conveyed verbally in a communication where the communicators are not confused or overwhelmed.

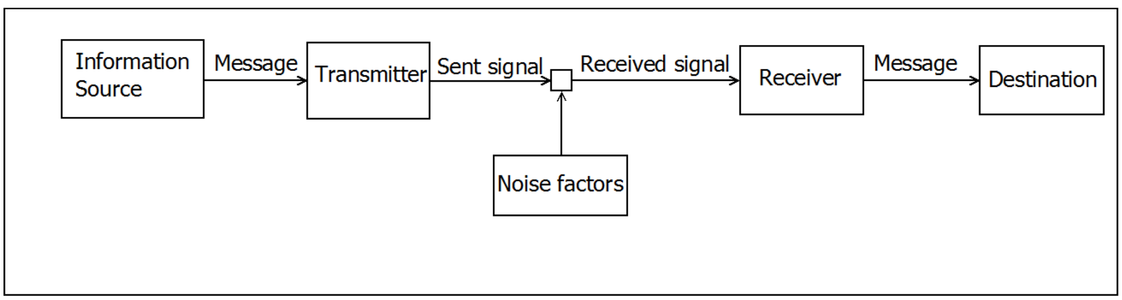


Figure 1 Shannon's Model of the Communication process (Adapted from Shannon, 1948 [60])

Some of the weaknesses of Shannon's model are that the model can only represent a fraction of human communication since there was other means of communication that must be taken into consideration. Also, the model does not define the term "information", and what are the differences between meaningful information and unrelated information. Finally, the model is static and linear which means the model views communication as the literal transmission of information from one source to the other, which is a false generalization. Even though a message can be correctly relayed and received, messages can be distorted or misinterpreted due to various factors such as tacit and explicit knowledge.

Moving on, the intermediary model introduces a “gatekeeper” between both communicators, gatekeepers act as liaisons or bridges between the speaker and audience. The main responsibility of gatekeepers is to provide selective sharing of information, in other words, gatekeepers receive all the information from the speaker then the information is filtered and then delivered to the audience. The limitation to this model is that gatekeepers must maintain high intuitive understanding of the subject of communication in order to determine which information to be released to the audience.

Figure 2 Intermediary model shows the use of a gatekeeper as a liaison person between the speaker and the audience (Adapted from Katz, 1957 [66])

Furthermore, the interactive model is an extension of Shannon’s model, a new component is added that is “feedback”. The key concept is that the recipient of information provides feedback on the message they received to the sender, that way the sender can confirm or alter the message in real time. The use of feedback introduces a strong and important communication component. Communicators can adapt their messages based on the feedback they receive while conversating and hence, the use of feedback in communication increase clarity and reduces the risk of misunderstandings.

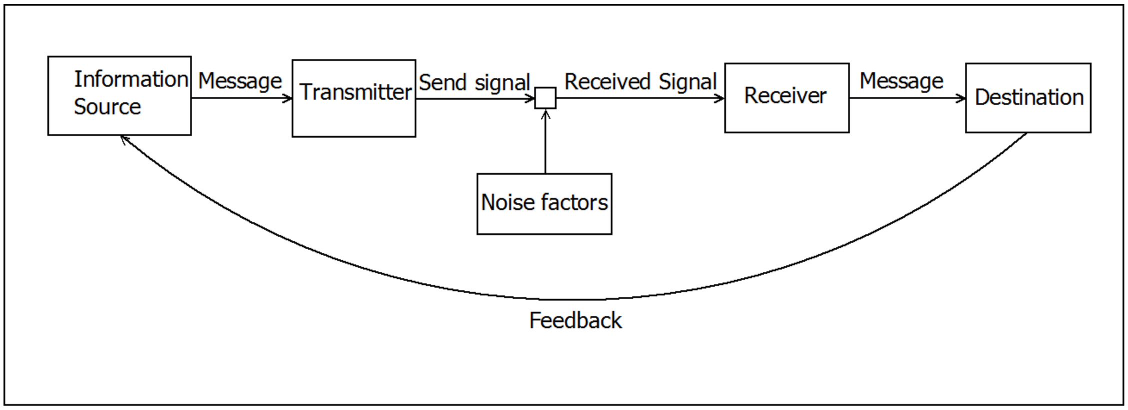


Figure 3 The interactive model highlights the importance of feedback in the communication process (Adapted from Foulger, 2004 [67])

The transactional model, shown in Figure 4 The transactional model acknowledges neither creators nor consumers of messages, preferring to label the people associated with the model as communicators who both create and consume messages. The model presumes additional symmetries as well, with each participant creating messages that are received by the other communicator. This is, in many ways, an excellent model of the face-to-face interactive process.

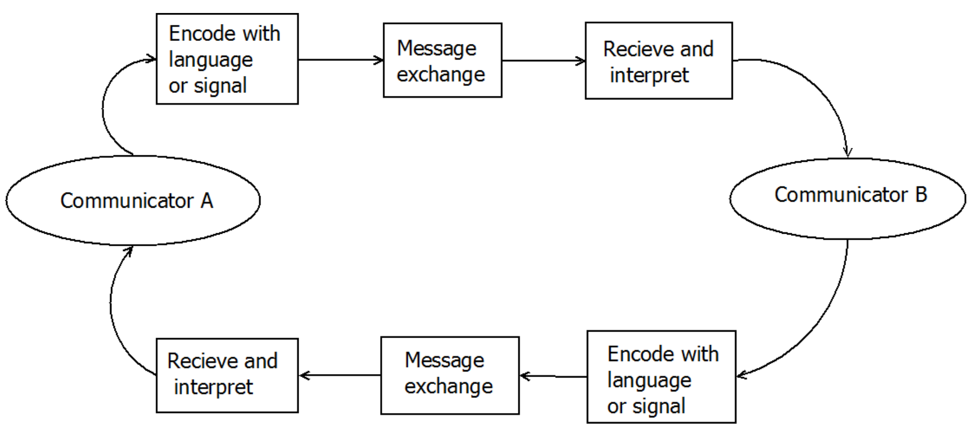


Figure 4 The transactional model introduces an additional symmetry with communicators participating in the communication (Adapted from Foulger, 2004 [67])

Moving on, an Ecological model of the communication process, Figure 5 The Ecological Model, asserts that communication occurs in the intersection of four fundamental constructs: communication between people (creators and consumers) is mediated by messages which are created using language within media; consumed from media and interpreted using language [67].

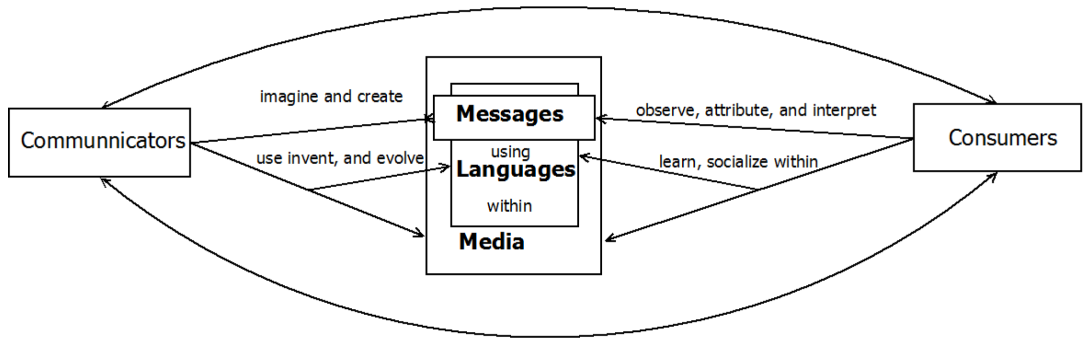


Figure 5 The Ecological Model shows the "who", "says what", "in what channel", to "whom" (Adapted by Foulger, 2004 [67])

Another model is Berlo's model; it implies that human communication is like machine communication, like signal-sending in telephone, television, computer, and radar systems. It even seems to stress that most problems in human communication can be solved by technical accuracy-by choosing the "right" symbols, preventing interference, and sending efficient messages. The model introduces new concepts of encoding and decoding, which emphasize the common challenge of translating ideas and thoughts into words and similarly, deciphering words into thoughts that make sense. Also, the model uses messages as the central object of the model, expressing the transmission of ideas between communicators. One of the weaknesses of the model is that is represents communication between humans as machines communicating, which is not true because humans add psychological, emotional, and cognitive factors to their conversations that machines do not acquire. The model suggests that using accurate terms and the correct terminology can solve miscommunication, even though that is true however, the correct terminology can be misinterpreted due to differences in education, culture, or experiences.

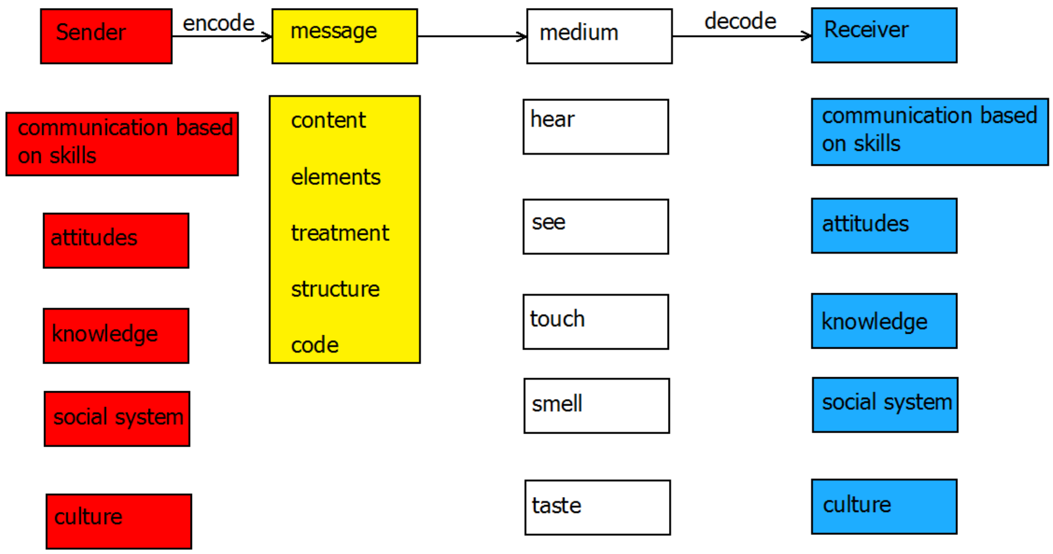


Figure 6 Berlo's Model (Adapted from Berlo, 1960 [61])

Next is the helix represents the way communication evolves in an individual from his birth to the existing moment. The helix implies that communication is a continuous, unrepeatable, and accumulative process that has no break in action, fixed beginning, no redundancy, and no clear closure. This model has too little variables which is considered as a limitation, which is problematic since this model asks a lot of questions but leaves many of them unanswered [63].

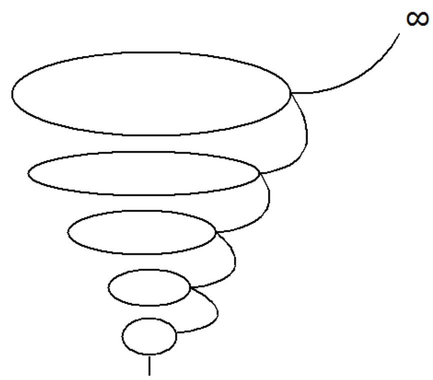


Figure 7 The Helical Model depicts communication as a dynamic process (Adapted from Dance, 1967 [68])

Another model is the coorientation model, which focuses on three main areas: (1) accuracy, (2) agreement, (3) congruency. Each of these concepts can be defined as follows:

- Accuracy: the degree to which A correctly perceives the regard B holds about X.
- Agreement: similarity of opinions held by A and B about X.
- Congruency: perceived agreement between A's opinion about X and what A believes is the opinion of B about X.

The model discusses the importance of how messages are formulated and how messages are perceived by the receiver by highlighting how communicators “think/feel” about the message being conveyed. The model does not discuss external noise factors that can also affect how messages are sent and received during communication, which forms a limitation to using this model.

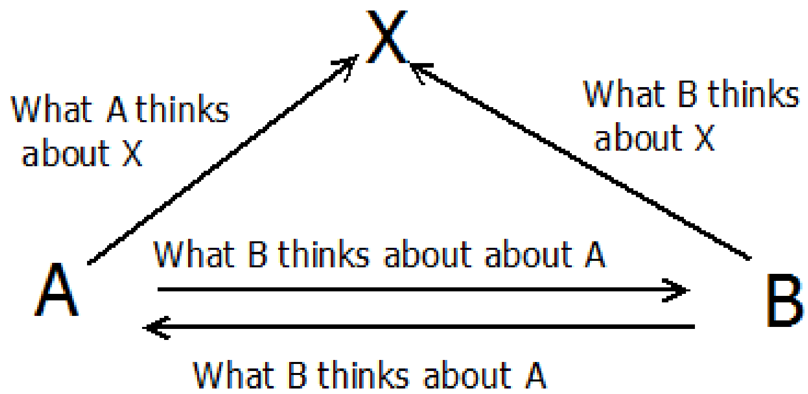


Figure 8 The coorientation model (Adapted from Newcomb, 1957 [69])

Table 5 shows some of the general communication models that can be potentially used to explain clinical communication. To determine whether a communication model can fit in Heath Care, we compared the models against reported medical error cases. From collected data, it seems that most communication problems occurred due to a noise of some sort and therefore, a model that does not take into effect the concept of noise while communicating was eliminated. After reviewing those models in Table 5, we decided that the closest model to Health Care is Shannon's model. However, Shannon's model can no fully adapt in a clinical settings therefore, we introduced a modified version of Shannon's communication model to be used as a communication model in Health Care.

Table 5 Analyzing general communication models

Communication Model	Summary	Noise included?	Applicable to Health Care	Reason
Shannon	Widely accepted	Yes	No	Too broad. Is

	as one of the main seeds out of which communication studies has grown.			concerned with sender's intentions rather than the process of interpretation.
Transactional	Acknowledges neither creators nor consumers of messages, preferring to label people as communicators.	No	No	Only applicable in face-to-face communication.
Ecological	Asserts that communication occurs in the intersection of four fundamental constructs.	Yes	No	Assumes that noise comes from the media which is not the case in Health care.
Berlo	Implies that human communication is like machine communication,	No	No	Stresses that most problems in human communication can be solved by preventing interference, and

	like signal-sending in telephone.			sending efficient messages. Those are possible solutions to a subset of communication problems in Health care but don't cover the majority of cases.
Helical	Represents the way communication evolves in an individual from his birth to the existing moment.	No	No	Too few variables. Also, hard to fit in Health Care due to the vague construction of the theory.
Shared experience	The overlapping fields of experience of the source and receiver show their perspectives.	No	No	Assumes that communicators should have overlapping fields of experience. That is never the case in Hospitals, physicians, nurses and clinicians

				all have different level of knowledge and experiences.

2.6 A need for a communication model

As the largest industry in the United States in 2006, the health care industry provides about 14 million jobs [40]. This shows the diversity in education, training and culture among employees. Therefore, a communication model that articulately demonstrates the communication framework among clinicians is essential. We believe that a communication model is a significant step towards improving the concept of communication in health care. By demonstrating a communication model, there will be more opportunities to raise questions and to encourage more research in this field. The model will show the complexity of the process and hence, display the order and coherence of procedures. Moreover, a practical model will open more research doors to new discoveries and better approaches about enhancing clinical communication which is our ultimate goal.

We expect the model to go through cycles of modifications and refinements as more cases are reported. However, our research does not stop at the model; in fact the model is just the beginning point in a roadmap to increase patient safety. Using the model, we plan to build ontology of possible clinical miscommunication causes which would help healthcare professionals understand medical incidents and increase their awareness of effective communication. The cases collected enable classification of communication factors at a lower level taxonomy. The communication model classifies the communication barriers and hence, provides higher level categorization of the communication model. Both, cases studied and the proposed model will provide a vision towards building a communication ontology which is more complete if sufficient resources are available.

2.7 H-H and H-C integration

The proposed methodology aims at encompassing areas of H-H and H-C interactions to study impacting factors on communication. In order to understand those interactions there needs to be a definitive meaning to what each interaction represents. The cognitive revolution theory provides an inclusive meaning to H-H interactions and reasoning for its inconsistencies. The theory looks into the knowledge an individual has to have in order for that individual to function properly as a member of an organization [70]. According to our experiences at the ICU, we find an agreement between the cognitive theory and our observations. Among the major contributing factors to H-H interactions is the type and size of knowledge a clinical has for example, the number of clinical years, the level of education and training, and the non-clinical knowledge that shapes an individual’s perception. Therefore, by looking at the ICU clinical team one can notice large differences in the nature of knowledge obtained by each individual. Moreover, within the team there can be a clear classification of two groups, the LP, and the rest of the team. The LP has cognitive properties that may not be present in other team members such as a richer knowledge base, wisdom based on knowledge, and a long history of practice. Within the rest of the team, there are also various cognitive properties, for example, a resident, while communicating, looks at the patient and the tasks to be performed differently than the pharmacist. The resident may have an inclusive overview of the patient's health status, needs, progress, and daily goals. A pharmacist, due to less patient interaction, may be interested in one corner of the patient's life, which is the medication list. Building on the points mentioned, we built our research hypothesis and specific aims 1 and 2, to study the impact of various cognitive theories on the clinical communication process.

Moving on, from a practical perspective, the H-C interaction (HCI) is the study of the design, development, and evaluation of computer systems to serve human needs [71]. However, this definition does not mention the science behind HCI, to reach an adequate understanding of this interaction cognitive science, namely the computational cognition theory, needs to be included [70]. This theory aims at learning the basis of processing information by using simulation models and behavioral experiments. Our interest goes beyond just learning the types of HCI in the ICU rather, the reasoning behind HCI behaviors and patterns. The ICU setting incorporates both interactions; the existence of Electronic Medical Records (EMR), electronic X-Rays, and patient monitoring computer systems, significantly facilitates or limits the quality of clinical outcome. Moreover, the presence of a clinical team, which can range from half a dozen to a dozen of clinicians, during patient rounds, introduces numerous on-site interactive behaviors. The famous Canada Air incident named Gimli Glider shows the importance of H-C interaction when an accident occurred due to a pilot error with the cockpit Fuel Quantity Indicator System (FQIS) [72]. Similarly, in health care, there is a need to prevent H-C interaction failures from occurring to avoid near misses scenarios, injuries, or deadly incidents. In one instance, Benny, a 14-month old baby, was admitted to the Pediatric ICU. The nurse received three verbal orders from the physician, the nurse made a mistake in recording one of the orders by recording 0.7mg of digoxin instead of 0.07mg. As a result of, the baby began vomiting and went into respiratory distress. Benny went into cardiac arrest and was announced dead after 55mins [73]. These supporting stories, among many other, highlights that in order to effectively study clinical communication our method must incorporate H-H and H-C interactions. Therefore, the aim of our study is to explore the impact of each interaction on the communication process by utilizing qualitative approaches.

The lack of utilizing adequate theory for HCI is considered as one of the factors to the modest progress made in the HCI field [74]. There are many HCI theories such as the situated action[74], the activity theory [75], distributed cognition [76], mental models [77], and ambiguity framework [78]. The theory of distributed cognition has been used to analyze and evaluate the relationship between representations in the real-world scenario [78]. Since this theory is not committed to a fixed method of analysis, one of its advantages is its ability to represent rich variety of elements in an organization's cognitive process. Distributed theory analyses can create concepts and relationships about human-computer interactions; this will generate an effective theory for design [76]. In a clinical team, distributed cognition would be very useful due to the existence of many concepts, relationships, and interactions, which needs to be represented in order to express the complexity and science behind communication interactions between team members. The benefit of this advantage is the development of a theoretical framework that will serve as an empirical basis for our research work. For that reason, distributed theory will serve as the scientific foundation of our research as we move from the theoretical to the practical frameworks.

Among the needs for effective communication are better managing of written and oral communication, understanding the barriers to effective communication, and exploring communication technology and its impact [79]. Also, in order to achieve effective communication, the adequate communication theory should be utilized by comparing theories such as the Bull's eye theory [80], Ping-Pong theory [81], and the spiral theory. As we contemplate about the needs and theories of effective communication, it is evident that in today's clinical settings the intertwined interactions among humans, and with technology, form the bulk of the communication process. From that perspective, there is a need to use a theory that views communication as the complex process that occurs between humans and technology-aided devices. Therefore, the closest theory to clinical communication is the Ping-Pong theory which views interactions as a complex linear cause and effect relationship between the sender and receiver. Through this theory, the definition of senders and receivers vary between humans and computers so that, the human-human interactions and human-computer interactions can be analyzed.

CHAPTER 3 - METHODS

Despite the significant impact of communication on the progress of health care services, only several promising attempts have been made to study and analyze underlying factors behind communication failures [34, 37, 52, 82, 83]. Nevertheless, there are still significant efforts needed to build a comprehensive informatics protocol that can extensively understand clinical communication. In an attempt to continue on from previous research discoveries, we have developed our methodology based on findings from two main sources: (1) literature, (2) preliminary observations at the ICU. Our methodology combines what previous research results suggest as well as insightful input from domain experts.

3.1 Specific Aims Plan

Despite the significance of clinical communication in research publications, there is a need to understand the theoretical motive behind the focus of this study. As a part of cognitive science, the distributed cognition theory, one of the most relevant theories to communication, seeks to further understand the structure of cognitive systems by focusing on individuals and organizations. The theory aims at rebuilding the cognitive system from the outside in, by looking at the social and materialistic settings and linking that with the knowledge inside individuals [71]. Following this scientific rational, the first specific aim was designed to study the external settings in which communication occurs specifically, by studying the interactions and interruptions caused by technology and humans. Then, the 2 and 3 specific aims study the use of tacit knowledge an LP acquires to communicate with the team, which can be measured through feedback and tasks performed by the LP. Moreover, the findings of ICU researches state that patients admitted to the ICU on weekends are at higher risk of death or will experience more complications than patients admitted on weekdays [17, 18]. We suspect that a contributing factor to those research findings is the variance in communication intensity and details on weekend days compared to weekend. Therefore, we intended to examine relationships and patterns between the data collected on weekdays and the corresponding data from weekends.

3.2 The proposed Communication Model

Based on systematic literature review and preliminary data collection pilot studies, this research has proposed the first clinical communication model which highlights communication factors, processes, and communicating parties [15]. Being the first model to delineate clinical communication, we expect this model to undergo further development, modifications, and verifications as we capture data and analyze model. A major aim of our efforts is to build a comprehensive data repository that resembles most, if not all, communication forms and factors. Scarcity of data forms a challenge to this research; therefore, we have proposed an innovative data collection methodology that will increase the scope of our efforts to include Human-Human Interactions (HHI) and Human-Computer Interactions (HCI) [84].

Since the proposal of the original communication model, the research team has been successful at capturing first hand data by observing at the Pulmonary Intensive Care Unit (PICU) at the University of Missouri [85]. The analysis of literature findings and first hand data has added significant insights to our communication model which in return added new factors to the model. Figure 1 shows the clinical communication model with new HHI and HCI factors under each category. Also, the model shows a new formulation of the exchanges of message such that during a conversation, any given message can experience a level of distortion when received at the recipient. The alteration of a message can occur in two ways, either by missing or adding details from the original message. Reasons for incomplete message transfer can be due to external noise factors, such as side conversations, or by technology-aided devices, such as pagers and computer alerts. As for the inclusion of new information or details to the original message, reasons can include the differences in tacit knowledge such as culture, training, clinical experience, and education. Among other contributing factors, the behavioral skill level of professionals impact the way of individual's communication in health care for example, we have observed that misunderstandings can occur during multi-tasking or various interruptions. Also, during HHI, the extensive use of memory is a major contributing factor to the quality of communication; the immense amounts of knowledge and patient information can be potential risks to communication breakdowns.

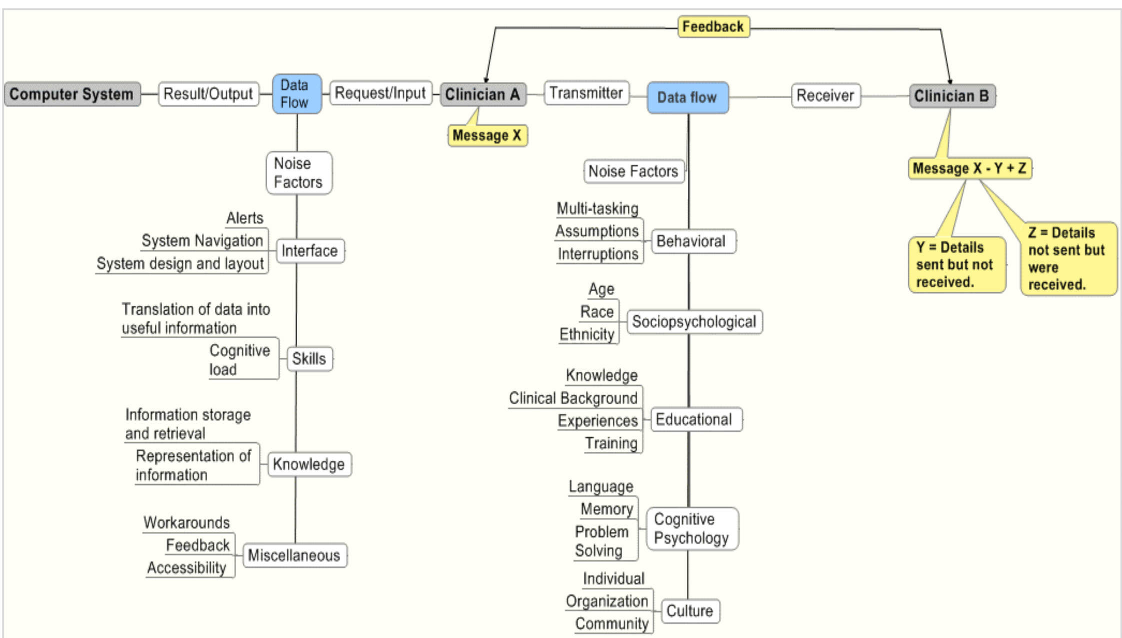


Figure 9 Modified clinical communication model with new subcategories and message exchange representation

On the other side, the communication mechanism between users and computer systems has many underlying factors that can lead to better communication quality. With regards to communication, HCI can be divided into two main components, users and computer systems. Users utilize the system to store or retrieve information, to perform these two functionalities, users require certain computer interaction skills. Among those skills, users need to be familiar with the system in order to enter the correct data into the correct fields. Also, users must be able to correctly retrieve and interpret information; this can be acquired with high practice and extensive system training. On the contrary, the need for user-centered systems design is paramount. The science behind usability patterns and behaviors should be the underlying science behind designing and developing clinical systems. For instance, the immense utilization of system alerts in some incidents cause users to ignore those warnings and to find workarounds. Therefore, further understanding of user skills and behaviors while using any clinical computer system will directly improve clinical communication from a HCI perspective.

3.3 Review of available research methods for clinical communication

Studies aimed at clinical communication have used different methods, such as grounded theory and statistical analysis, to model and analyze the communication process among professionals. Results from those studies agree that there are communication barriers that need to be improved to enhance the level of interactions between professionals. However, while different experimental approaches such as observations, interviews, and focus studies, have been utilized in those studies, we believe that there is still a gap between current findings and the level of knowledge required to build a knowledge base that can enhance communication. Through reviewing related research, we conducted a literature review that highlights the strengths and weaknesses of the methods being utilized. The aim is, through understanding current research methods, to propose a combined research method that can fragment the efforts of researchers into one research that is able to yield more robust and comprehensive results.

A repository of approximately 20 researches from 1996 was created; the inclusion criterion included studies focusing on communication in health care in general and within the ICU specifically. We carefully studied the methods used. 13 publications used a two-step approach of an observational study followed by semi-structured interviews. Other publications used focus groups, or either an observational study or interviews. Tables 1-5 show samples of research methods that represent each experimental category.

Table 6. Sample paper using an observational study followed by semi-structured interviews[86]

Title	Clinical communication in a Trauma Intensive Care Unit (ICU): a case study
Methods	• Subjects were shadowed for 12 hours shifts • Observer noted all communication events. • Subjects were interviewed to obtain clarification of events • A further interview with the medical director and in charge nurse about the history of communication and its support tools
Strengths	• Provides clear breakdown of the ICU team activities • Interviews provide relevant information that was not captured during the observational study
Limitations	• No data verification • Duration of the study was not sufficient (12 hours) • Results from the observation provide insufficient analysis of the relationship between communication events and errors

Studies that conducted an observational study followed by semi-structured interviews demonstrated a robust performance. However, in general, results should be verified against results from other sources for higher levels of reliability and validity.

Moreover, many studies in that category capture important communication factors but, the attempt to improve communication at whole is a complex approach. We believe that through breaking down the communication problem into finer levels, the analysis and improvement steps can be more effective.

Table 7. Sample paper using an observational Study [87]

Title	Communication failures in the operating room: an observational classification of recurrent types and effects
Methods	• Over 3 months, 90 hours of observation were conducted during 48 procedures in general and vascular surgery • Used two phases of analysis: o Phase 1: define parameters of comm. failure. o Phase 2: find trends in type of exchange and effects on system process
Strengths	• Use of domain experts to analyze collected data • The observational study revealed important causes for miscommunication through defining four communication factors
Limitations	• Results may be affected by the sample bias among OR team participants • Only 36.4% of communication failures resulted in immediate effects which were visible to observer

The other type of studies implemented an observational protocol to further understand communication problems. Through shadowing the clinical team, many communication events and behaviors were captured; one of the main contributions of these studies is the use of domain expert to validate and verify the information captured. The quality of the results can be significantly improved through the utilization of an expert who determines the quality and accuracy of the data collected. Also, experts are able to transform collected data into meaningful information through observing patterns and predicting trends. The challenge of solely depending on shadowing the team is that only a minor segment of communication failures can be captured by the researcher and hence, the level of exhaustion will be limited and many communication events will be left out.

Table 8. Sample paper using interviews and surveys [52]

Title	Improving Communication in the ICU Using Daily Goals
Methods	• ICU team members were surveyed and interviewed to estimate the magnitude of the communication problem • A form was designed to facilitate communication by requiring the care team to define explicitly the goals for the day • Each day the resident and nurse caring for 2 patients were surveyed for 8 weeks
Strengths	• Providing a clinical tool is one structured way towards improving communication • The duration of the study was sufficient to cover wide range of ICU teams
Limitations	• Human-Human and Human-computer interaction assessments are missing • The surveys heavily focus on residents and nurses within the team

The next category of articles depends on interviewing and surveying participants to gain knowledge about communication performance levels. Usually, this methodology is used when a certain tool or protocol is implemented in the ICU and the success of this tool needs to be assessed. This approach provides limited information on the causes of miscommunication since the questions can be bias towards a certain direction, therefore, we believe that using interviews and surveys towards assessing the educational tool we plan to implement in the future, served well this research. Since there is a challenge to recall incidents after they occur, the use of interviews and surveys alone can limit the our understanding of communication to the information provided by clinicians, the need for first hand data is essential to validate the information given during interviews and surveys.

Table 9. Sample paper using focus groups and surveys [82, 88]

Title	Perceived information needs and communication difficulties of inpatient physicians and nurses
Methods	• Conducted a survey and 5 focus group sessions of inpatient physicians and nurses • Electronic survey was provided for physicians and paper format for nurses • 3 focus groups for physicians and 2 focus groups for nurses
Strengths	• Professionals highlighted important communication difficulties based on domain area and expertise level • Focus groups provided information that can be hard to capture during observational study
Limitations	• Data collected depends on cognitive skills rather than first hand data • Response rates from surveys were relatively low (21% physicians, 24% nurses)

Focus groups and surveys represent another category in the available research methods. The benefit of using focus groups is giving the opportunity for professionals to unwind their clinical experiences and a frustration with regards to communication which is represents an efficient way of collecting data. Most information provided during focus groups heavily rely on cognitive skills which forms a challenge because clinical routine is hard to recall. Moreover, focus groups are isolated from the work setting which can limit the amount of incidents a clinician can remember, limiting the scope of the communication problem to what they can recall. Moreover, the use of surveys might not be the efficient way of collecting data because of the relatively low response rate, there needs to be an alternative primary source for collecting data other than surveys.

Table 10. Sample paper using literature review [83]

Title	Interdisciplinary communication: An uncharted source of medical error?
Methods	• Performed a literature review using clinical databases • Search keywords focused on medical errors and communication

	• Articles reviewed focused on clinical team activities, provider-patient articles were excluded.
Strengths	• Provides a constructive overview of the clinical communication problem • Focuses on communication within ICU • Top communication difficulties for Physicians and Nurses were identified
Limitations	• The study integrates results and findings from other study; there is a need for first hand data • No clear solution to challenges stated in the study

Finally, the use of literature review to further understand communication is a well-structured method that provides previous work, current efforts, and the future direction towards solving the problem. In order for any research to be successful, researchers must understand the previously mentioned components of the problem. However, without acquiring data, the ability to build a knowledge base is bound to previous findings which limit the level of progress of any research. Through collecting data, a better understanding can be developed and new innovative ideas can arise. The use of literature review is essential for any research, we utilize this method in the early stages of this research as a part of our mission to comprehend and improve clinical communication.

Researchers have provided significant efforts towards improving clinical communication through the implementation of previously mentioned research methods. Each of those methods offer unique data collection approaches and their results show their success within the ICU. However, the challenges available in each method form a barrier to our goal of further understanding clinical communication. For that reason, we aim at developing a research approach that consolidates several of those research methods together while eliminating many limitations.

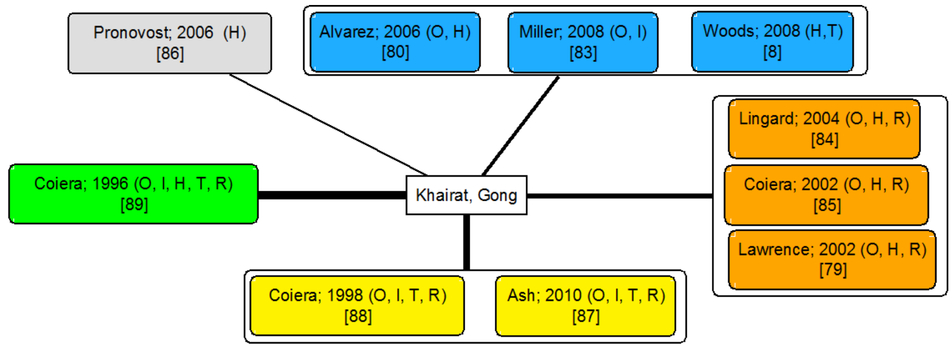
3.4 Suggestions from previous communication research

For over a decade, researchers have been studying clinical communication in various directions, yet as discussed earlier the current communication state is far from expectations. In order to develop an efficient methodology approach, there needs to be a systematic understanding and assessment of previous efforts. For this purpose, we generated a pool of clinical communication literature including more than fifty research papers since 1996 and we created a shortlist of ten papers that we believe are the most relevant and inclusive of the problem. The main goals are to study the approaches, results, and suggested work of each research and also, build a roadmap that can increase the depth and breadth of our research scope. In order to do so, we focus on a two-dimensional view: vertical and horizontal view. By breaking down communication categories into finer subcategories, the depth of our research reach into the problem maximized. The horizontal view focuses on increasing the problem spectrum to include various clinicians, communication mediums, and tools and hence, increase our outreach.

The inclusion criterion of papers was based off five major components. First, we identified papers that conducted observational studies at health organizations; the reasoning behind observational studies is that first hand data strengthens the accuracy of results and provides more applicable knowledge. Second, we believe that conducting semi-structured interviews is necessary to reveal rare patterns and provides personal feedback from subjects. Furthermore, communication in health care consists of two main elements: human-human and human-computer interactions; those formulate the third and fourth components. Lastly, we included papers that proposed future directions to be conducted in this field. This criterion is of importance to show the view of experts on the bridge between current findings and the expected state of research and hence, provides a roadmap of the communication process.

In order to increase the yield of our study, we systematically studied the methods used in those selected researches. Most researches proposed a two-step approach; an observational study followed by semi-structured interviews. We favor this approach due to its ability to provide first hand as well as obtain clarifications and feedback from subjects through interviews. In order to relate our research with previous work, we drew a proximity map that displays the relevance between other researches and ours. Figure 2 shows the ranking process which is based off a 5-point system. Each paper was analyzed and ranked according to the five inclusion criteria above mentioned, with 5 points being the most relevant. The relevance of each paper or category can be shown through the size of the arrows; the closer a category is to our research, the thicker the pointing arrow. Author's name and year of publication of each research paper are used to identify various researches. After the author's name and year of publication, we identify the areas of strength of each paper by denoting a single letter for each topic. The description of each letter can be found in the weighting scale at the bottom of the diagram. Finally, the numbers between brackets represent the reference number of each paper in our manuscript.

While those researches used well-constructed methodologies and yielded remarkable results, we identified essential factors that, if added, can enhance results and improve understanding. Also, some studies focus on one aspect of communication, that is either human-human or human-computer interaction. We believe there is a necessity to study and integrate both components together especially, since many health care organizations indulge both interactions in their daily routine. The number of hours spent shadowing subjects and the number of research assistants varied among studies, however, most studies focus on physicians and nurses only. We strongly believe that in order to obtain a more comprehensive understanding, the consideration of clinicians from other specialties is essential, and the development of a detailed actionable plan is within this research's future work scope. The recently proposed clinical communication model [15] has demonstrated major key concepts in the communication process. The model represents influential factors among clinicians as well as between clinicians and computer systems. The model shows that technology has a pivotal role in communication but nevertheless there are limitations and challenges related to computer systems and user skills that need to be improved in order to improve human-computer interaction. Through the analysis of literature review and first hand data, we aim at further tuning of the model to maximize its level of coverage and also, highlight major and minor contributing factors to errors.



Weighting Scale

Topic	Points
Observational Study (O)	1
Interview (I)	1
Measurements include human factors (H)	1
Measurements include technological factors (T)	1
Future work relevant to current research (R)	1
Total Points	5

Figure 10 The relevance of previous researches to our research. (Thicker arrows represent linearly proportion) [8, 82, 83, 86-92]

3.5 The ICU Setting

The collection and analysis of reported communication error cases are valuable and rich in information; however, the comprehensiveness provided by first hand data forms a necessity to conduct an observational study at the ICU. In order to design a methodology that captures real-time clinical communication instances during patient rounds at the ICU, a clear understanding of the structure and setting of the ICU rooms needs to be developed. For that reason, the clinical team conducted a pilot study for three days exploring and observing the ICU setting, the nature of the patient rounds, and communication among the clinical team.

The design and development of our observational checklist instrument was built to fit the ICU environment. In order to collect meaningful data from our ICU study, it is essential to clearly understand the structure of the ICU patient room, the available resources on site, and the structure of the clinical team. For that reason, we carried out the pilot study to further analyze the setting and also, we captured pictures of empty patient rooms to further understand the available resources that can potentially impact the communication process. Figure 11 shows a schematic of the ICU room including a common scenario during patient visit.

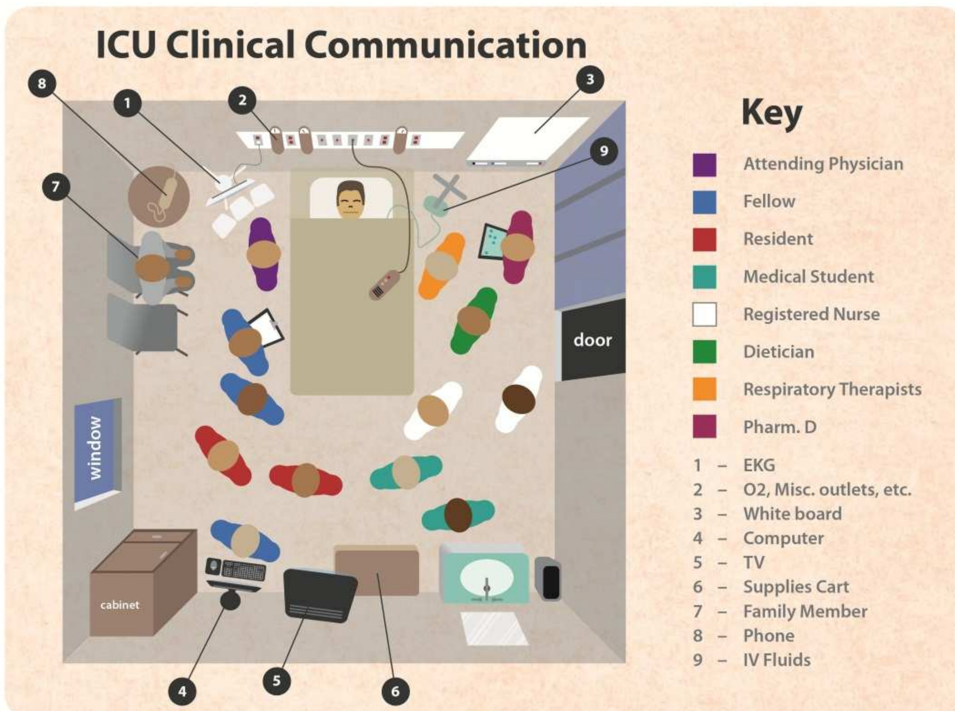


Figure 11 A schematic of the ICU patient room including an approximate representation of the clinical team

Upon entering the patient room, the clinical team, which varies in size, gathers around the bed to discuss the latest patient status and to determine daily goals. The clinical team is led by the Attending physician and it consists of Fellows, Residents, Registered Nurses, Medical Students, Respiratory Therapists, Dietician, and Pharmacists. As the team enters the room, team members utilize the Computer-On-Wheels (COW), available in the room, and their laptops to retrieve the latest vital signs and lab tests and to store any new orders. The Resident assigned to the patient begins the communication by giving a detailed description of the patient status, updates on the case, and discusses their future tasks and goals for this patient. As the Attending physician and the team tentatively listen, we captured certain interruptions that occurred either from clinicians or technology-aided devices. After the detailed explanation of the case, the Attending physician leads a discussion that is aimed to provide teaching lessons, latest research updates, and the goals for this patient.

Looking into the available resources in ICU rooms, each room is highly equipped with technological advances such as computer systems, monitoring systems, TV, and telephone. Those devices play an important role in communication either by facilitating storing and retrieving information, or by limiting communication through numerous sound alerts. The impact of technology-aided devices is an essential component in our mission to further understand clinical communication. For that reason, we divide our research concentration into studying clinician-clinician and clinician-computer interaction.

3.6 Data collection plan

This research aims at undergoing a systematic process of transforming current data into meaningful information and then, transferring information into useful knowledge that can be used in education, training, and error report systems. Our data collection plan consolidated previously reported communication failure cases and data generated from our observational study. This repository of data was used to increase the validity of our findings through mapping similar communication cases together.

3.7 Observational study design

The location and specialty chosen for this study were selected based on certain criteria. Communication practices are various, and a location that can capture most communication practices would be most preferable. The University of Missouri Hospital offers primary, secondary, and tertiary health care services, and it provides formal academic teaching and constructive research services. Considered as a national leader in health care quality improvement and quality patient care, the level of adherence to national health care standards and regulations are guaranteed and thus, the quality of trained staff and resources provided a fair environment that can be extrapolated to other large health care institutes. Moving on to our specialty choice, we chose to observe at the ICU, specifically Pulmonary ICU (PICU), for its critical patients' condition, and its quick and rapid scenarios. Since research calls for more research aim at ICU communication, we believe that the ICU as a structure and an environment that provide important information that can only be obtained from critical care departments. Also, medical errors at the ICU are critical and their consequences can vary from near misses to injuries and possibly deaths. This study does not aim at capturing medical errors at the ICU; rather, we aim at capturing communication trends and behaviors that can potentially be the cause of medical errors. Therefore, by observing and understanding the communication nature at the critical care level, fewer errors will be made and hopefully, safer care can be provided to patients.

Eventually, this study will record and analyze clinical communication from the perception of each team member. The ICU team includes, but not limited to, an Attending or a Lead Physician (LP), Resident, Fellow, Respiratory Therapist (RT), Registered Nurse, Physician Assistant (PA), Nurse Practitioner (NP). As a starter, the Attending physician, also known as the Lead Physician (LP), was the primary focus of our research; LPs initiate and carry most communication events among the team. By shadowing the LP, we are able to capture most communication trends and patterns that occur within the team since the LP is usually a significant participant in the communication. The aim of this study is to shadow 3-5 Lead Physicians over a course of 6-10 weeks. Each LP has a two-week rotation at the ICU, and each LP was observed 6 times during that period. To increase the reach of this research, the six days of observation are distributed as follows:

- First day of the first week
- Two days during the weekend
- Two week days
- Last day of the second week

This distribution was suggested by ICU domain experts as well as by our research biostatistician. From a clinical point of view, the first and last day of the 2-week rotations would capture the communication patterns during a chaotic first day and then, the more organized communication found at the end of the rotation period. Also, weekends provide a different pace and intensity than week days which might reveal interesting relationships. Statistically, if we treat physicians as a treatment and repeat the observation of the same LP during different day would increase the reach of the research and it would increase the validity of the data.

The ultimate plan is to capture communication patterns during the morning rounds, since it is the time when the clinical team gathers to discuss ICU patients. To increase the validity of this research, two clinical researchers simultaneously shadowed the LP during bed round sessions. The decision has been made to utilize observers with no medical, especially ICU, background; the reasoning behind this is to ensure that the observational process is free of any bias and the observers have no clinical experience or knowledge that might distort or affect their judgments. Both observers used the same observational checklist we built to record what they observe, communication between the observers was restricted during the observation to limit the introduction of any biases. Based on trial ICU observations we conducted, it is evident that two observers capture more data and on occasions, one observer recorded instances that the other person missed. This increased the validity of the data being captured as well as it adds a higher degree of accuracy to the findings of this research.

The observational study has two components: (1) observation, (2) survey questions. During the observation session the two researchers shadowed the clinical team through bed rounds; the researchers utilized the ICU tool to capture communication instances of the LP. During each patient visit, the researchers were in the patient room with the clinical team; the aim of the researchers is to monitor and record communication events of interest. Researchers were within close proximity to the LP without causing any distractions or noise, the location of the researchers is of importance in order to observe the majority of LP communication behavior as well as to be aware of surrounding environment that might introduce noise factors to the communication.

After the bed rounds session, the two researchers asked the team to participate in the survey. The idea of the survey is to know their level of satisfaction, confidence, and participation in the communication process. Also, the survey aims at assessing the effectiveness of the clinical communication throughout the day from the team's perspective. This survey was used as a baseline measurement that can be used to measure and compare the quality of communication. We are not interested in collecting any unique identifiers from interviewers however, it is essential to know the role of each interviewer in the clinical team. Ultimately, we are interested in exploring potential relationships between years of experience, training, and education and their impact on communication.

3.8 ICU Communication tool development

The research instrument used in this research underwent 12 iterations of modifications to improve the structure and contents of the instrument. The changes made were based off a series of trial sessions conducted at the ICU. At the beginning the instrument included fewer high level categories (table 9) that limited the type of data captured. Regardless of the fewer categories in the initial instrument, each category was broken into high level communication factors that were overlapping and in certain instances incomplete. For instance, the human interruptions category included 4 communication factors, 3 of which provide inconsistency and a significant amount of overlap as to who caused the interruption. Also, for the technology interruptions, the initial instrument showed incompatibility of the real-time scenario at the ICU. For example, telephone calls usually do not occur during patient rounds and the differentiation between text messages and emails on smartphones are challenging without examining the phone. There was an interest to monitor post-interruption behavior of the LP, however, after several trials; we believe it is a challenge to differentiate between a new thread and the same thread. We define a thread as part of the discussion that focuses on a certain point or concern. Since our observers are not clinicians, their judgments may be vulnerable to errors or misinterpretation. Therefore, this category has not been included in the study to avoid inaccurate findings, with the intention to study this category in future work.

Table 11 Clinical communication categories used in the initial versions of the instrument.

Communication	Communication factors	Measurement
Demographics	• LP initials • Date • Observer initials	Text / Date
Human Interruptions	• Type of questions • Side conversations • Verbal Alert by Nurse • External interruption by other	Tallies
Technology Interruptions	• Alerts ○ Bed-side system ○ Phone calls ○ Computer alert • Pager • Cell phones • Text messages	Tallies
LP action post interruption	• Same task • New task ○ New thread	Tallies
Repetitions by LP	• Frequency	Tallies

The 12 versions where developed over the course of 6 months, the changes included the addition of essential communication factors that were not in the original instrument, the use of better descriptive naming terminology, and the rearrangement of categories based on the actual chronology of LP tasks. Researchers made suggestions and comments during the trials which were discussed after the trials and changes were made.

Since similar ICU instruments are hard to obtain from literature, we designed our instrument based on certain factors identified in literature as well as, our domain expert's expectations of communication behaviors at the ICU. However, the trial study we conducted added valuable first-hand experience that suggested major changes to be done to the instrument to ensure high quality of data.

Final instrument

After many versions and multiple trials of testing the instrument at the ICU, the instrument reached a level of maturity and communication categories were independent and exhaustive. We realized that minor changes can be made at the beginning of data collection however; we decided that no major changes should take place to maintain the level of reliability and validity of the data. As shown in Table 2, the final instrument is designed to capture 7 main communication categories. Each of those categories is broken down into finer levels to yield higher quality of data. The finding of our preliminary ICU study suggests the addition of important categories such as interruptions, feedback have significant impacts on the communication process[33]. The basic demographical information provided in the initial instrument showed limitations during preliminary data analysis. The aim is to capture more information about the number of patients during each day of observation, the clinical team size, the time for each patient visit, and to record the observers initial. In addition, we observed the importance of feedback and how it can be used for different purposes such as to give instructions or to teach medical students. Therefore, these factors were included in the final instrument to maximize the opportunities of finding patterns, trends, and relationships.

Furthermore, the significance of human and technology interruptions mentioned in research suggested that we reorganize how we identified interruptions[34]. Human and technology interruptions were captured differently from the initial instrument in two ways: (1) the communication factors, (2) the measurements. As we spent more time at the ICU, we could better identify the types of interruptions that occurred and hence, a well-defined set of factors were established that ensured minimal overlap and higher applicability. Also, the measurement type in older versions consisted of frequencies only, which limited our work to quantitative research type. So, in an attempt to increase our findings, the measurements for interruptions were modified from tallies to recording the response of the LP to the interruption by recording "A" for accept and "R" for reject. This way we are able to capture the frequency of different interruptions and the impact of those interruptions on the communication effectiveness of the LP.

Also, as discussed before, the H-C interaction is an essential category to monitor and assess and hence, the H-C category was added to the instrument with extra details that has been observed during the testing trials. This category was added in final versions of the instrument. At the beginning, the category included whether the LP read information on the screen or interacted with the computer. However, this classification would only yield quantitative information again so; we divided the H-C interaction into two factors: (1) read-only, (2) interactions. The read-only factor is recorded as information (I) or X-Ray (X). The information factor means the LP read patient information whether it is from the Electronic Medical Record (EMR) or one of the monitors in the room, while the X-Ray factor means the LP viewed the patients X-Ray stored in the EMR. As for the interactions, there are two interactions, the LP can use the

Mouse (M) or the Keyboard (K) to store or retrieve data. Each time the LP uses one of these two interaction devices, the observers record the device prefix, that way the frequency and type of computer interaction were captured.

In addition, we believe that it is essential to further understand the role communication plays in the nature of the LP job. One way to do so is by understanding the nature of tasks that the LP conducts. Through observation, we identified four categories that we believe cover the majority of tasks done by LP during patient rounds at the ICU. We are interested in studying the most and least frequent activity done by the LP, so the measurement type for that category is frequency. One of our aims is to find relationships between the type of tasks an LP does and the years of experience, and clinical background and training. Finally, we added an important category that records the frequency of slips or mistakes done by the LP or other team members. Since we are only observing the LP in this study, we are interested in the mistakes made by them. We record two types of slips, the first is when the LP makes a mistake and then corrects themselves, and the other when another clinicians correct the LP. The goal is to study the frequency of clinical team members of speaking up and correcting the LP, and the frequency of successful cognitive use by the LP to correct their slips.

Besides significant category changes in the instrument, minor changes were made in the instrument to facilitate the data recording process. The instrument was designed to fit the chronological order of tasks inside the patient room, that way observers can systemically record the data by going through the instrument from a top-bottom approach. Also, some of the terminologies used to describe categories and factors caused confusion to the observers during trial sessions because some of the naming conventions appeared to overlap and so, observers were challenged as to where certain instances would be recorded. Prior to the trial sessions, changes were made to the terminologies on the instrument in order to ensure clearness and independencies between the different communication factors.

Table 12. Clinical communication categories used in the ICU instrument

Communication Categories	Communication factors	Measurement type
Demographics	• LP initials • Team size • Date • Patient number • Time at the beginning of Patient visit	Text / Date / Numbers
Feedback to LP	• Verbal • Non-Verbal	Frequency
Human Interruptions	• Type of questions • Side conversations • Non-Clinical team personnel	Accept / Reject
Technology Interruptions	• Computer alerts • Pager • Cell phones	Accept / Reject
Human-Computer Interactions	• Read-only • Interaction	• Information / X-Ray • Mouse / Keyboard
LP Tasks	• Give Information • Request Patient info • Request new task • Teaching	Frequency
Corrections	• LP corrects themselves • Team member corrects LP	Frequency

After the tool has been tested and ready for deployment, a plan has been made to outline how the data captured can be used to meet each specific aim of this study. The first specific aim was measured by looking at two sections in the tool: human interruptions, and technology-aided interruptions. Both sections are broken down into finer levels to further analyze the effect of each factor. The baseline measurement for this aim was be the first survey question which tackles how well the clinical team comprehends their daily tasks. We believe there is a relationship between the level of interruptions and the ability of the LP to deliver their messages. The second specific aim focused on the data recorded in the feedback section which records the frequency of verbal and non-verbal feedback In order to understand if the amount of feedback enhances the quality of communication, we aim at using the second question in the survey as a baseline measurement. This questions measures the quality of answers provided by LP, the correlation investigated relationships between the frequency of feedback and the level of understanding at the team members. The third specific aim looks at the LP tasks section in the tool, by comparing the various tasks performed by the LP and answers from survey question number 3, we can find out what LP tasks limit two way communications. Question 3 is aimed at assessing the amount of time the LP provides for questions and concerns from other team members. Finally, the fourth specific aim was tackled differently; the plan is not to compare the checklist against survey questions however, to compare checklist results on weekends against checklist results on weekdays, then compare the weekend survey results against weekdays survey results. The reason for this change is because we are interested in studying the communication behaviors on weekends and weekdays from one side, and on another side, study the level of communication satisfaction on weekends compared to weekdays, specifically by looking at survey question 4.

3.9 Data Digitization

Upon data collection, an important step is determining how to digitize data in order to begin analysis. Our research aims at yielding statistically significant results; also, an additional aim is to build a well-structured knowledge base that can be used to derive inferences and to build associations and relationships across time as our research in the area of clinical team communication continues. Thus, the conversion of data into matrices or spreadsheets would relatively limit the ongoing process of knowledge discovery. Therefore, we have used MySQL as our Database Management Systems (DBMS) to digitize, organize and analyze our data. The use of a DBMS provides much powerful functionality such as the organization of data into tables, the ability to create views to bridge information from various tables, and the means to discover relationships between communication categories.

We created a local environment that comprises MySQL 5.0, Apache web server 2.2, and PHP 5.2. This combination of instruments facilitates the automation of over 500 data collection sheets of data into a well-structured database of nine tables. Hypertext Preprocessor (PHP) is a general-purpose scripting language that is suited for web development and is known for its powerful interactivity with DBMS. Apache is web server software known for implementing complied modules to support common languages such as PHP and Python. Apache serves as a mediator between PHP and MySQL by interpreting commands from PHP and then sending and retrieving information to and from each component. PHP scripts were written to organize the data into a format readable by the database and insert the data into the correct tables.

The digitization process occurred simultaneously as data was being recorded. After each study, the primary researcher collects the data collection instruments of the day, plus the survey answers from the team. The database is prepopulated with the Attending's information, the clinical roles present in the team, and the two researchers collecting data to facilitate data entry. The For each study, the research input the information related to that specific study, such as the date, Attending's ID, team size, and the number of patients seen during the study. It is necessary that the study information is inserted into the database before entering any observations or surveys; this is because each observation and survey belongs to a unique study, and if the study is not already available in the database then, this relationship cannot be established. Then, the researcher enters the data captured during the observation into four tables. The Observation table records all the quantitative communication variables, the other three tables capture the qualitative variables such as the response to an interruption. For each study, the observation data is categorized into two piles, each pile includes the data collected by each researcher. After that, the researcher enters all the observation data collected by researcher 1, followed by the data collected by researcher 2.

Once all the observation data has been stored in the database, the researcher moves on to entering the survey results. Survey data is stored in one table and it is linked with the study table in order to maintain a unique relationship between the surveys and a single unique study. In other words, one study can have multiple survey results however; one survey cannot belong to multiple studies. The researcher records the date of the survey, the role of the participant, and their answers to the four survey questions. The open ended question is not included in the statistical analysis section however; it was included in qualitative analysis.

The process of building a data repository included multiple steps. Initially, all data recorded by the two observers and the accompanying survey responses were recorded in a database. Then, a new database was created to include the aggregate data from the observers; in other words, instead of two entries per patient visit, there would be only one. To create this aggregate, the average score was taken for each variable and the ceiling was applied to the average to maintain whole numbers. The reasoning behind using the ceiling function is that observers usually under count rather than over count, due to their inability to capture and record all simultaneous events. After that, another database was created to include the aggregate of all variables for a whole day rather than multiple entries per day. This database was the source of most statistical analysis because each patient visit was considered a unit of treatment rather than the number of days. Fourteen PHP scripts were written to transform data from the raw material to a more structured format, which was then stored in the three databases. The reason we maintain all databases is our belief that raw data is the foundation of this research, and it should be maintained for the sake of reverse engineering or reverse hypothesis generation.

During data collection period, data captured was transformed from the paper-based instrument into electronic format through the utilization of a database system. The database schema shown in Figure 2, consisting of nine tables, is designed to capture all the data from the ICU study into one repository that facilitated further analysis. The attending physicians' information is stored in a separate table. Each day at the ICU is treated as a unique data entry point, since we examine communication per day; each study has two tables associated with it, one for the data collected during observation and another table for that day's survey results. Table Survey is designed to store the role of the participant, the date, and the responses for the four Likert questions. Answers on the Likert scale was converted into a scale from 1 to 5, 1 being "disagree" and 5 being "agree." Questions 2 and 3 have two parts to them: If the answer to the first sub-question is yes then; there is an additional sub-question is to be answered. So, if the first part of the question was answered "no", then a null value is recorded. If the answer was "yes" then the answer depended on the respondent's Likert-scale choice.

The complexity of data captured during observation generated four weak entities associated to the observation table, shown in dashed border lines. A weak entity is a table that cannot exist if the main table, i.e. observation, does not exist. Table Observation stores the quantitative variables whose values are based on frequency. Table Roles is used to identify which observer recorded the corresponding observations. The other tables store qualitative information about human and technology interruptions, and computer interactions. The variables stored in the weak entities include more than frequencies; we want to know the response of the attending physician to interruptions and the types of computer interactions. During the occurrence of either a human or technology interruption we capture the response of the attending physician to the interruption by recording an "A" for accept or an "R" for reject." Table ComputerInteractions records the types of interaction an attending physician has with the computer station available in the room. These interactions are can be either reading information on the screen or physically interacting with the computer. The reading information category is broken into two finer levels: reading patient information or reading an x-ray. The interaction category records the frequency and whether or not the attending physician is using either a mouse or keyboard.

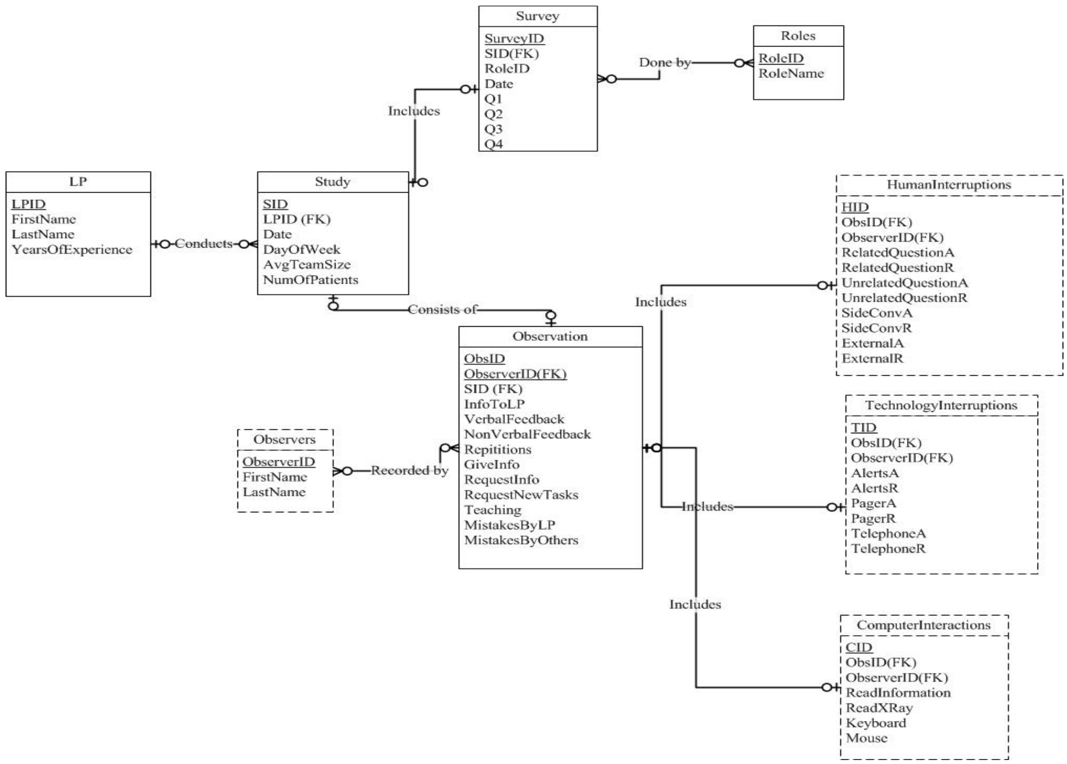


Figure. 12 Entity-Relation Diagram of Communication Database

3.10 Data Analysis

Since this research collects data from various sources, there is a need to consolidate this data to increase the level of validity of data. We understand that data collected from literature is not complete and the observational study we conducted provided new communication cases. Therefore, we aim at reviewing data collected by a domain expert. Domain experts provided feedback on the validity of communication factors, the accuracy of results from the observation and surveys, and they ensured that the data is relevant to the scope of the problem. The main challenge of this research is gathering data that represents the majority of communication events among clinicians. As mentioned before, literature does not provide a complete knowledge representation of clinical communication. In this research, our main goal is to develop a communication framework through analyzing a consistent and comprehensive data pool. The evolving nature of health care represents an obstacle towards building a complete framework; however, we aim at establishing the fundamentals of clinical communication to which future additions can be made to.

We view data reliability and validity as critically important factors towards fully understanding clinical communication. To ensure validity, which is the degree truthfulness to which a variable can measure an intended phenomenon, we plan to use content validity approach. This approach requires researchers to identify the overall represented content namely, communication factors in the tool. Identifying the realm of the content is a challenging task therefore; the input of domain experts were included to precisely identify factors of interest. Furthermore, the reliability of this research concerns the extent to which the instrument yields the same results on repeated trials. After reviewing reliability methods, we believe the retest method is the most applicable to our work. The retest method suggests providing the same testing methods to the same group of people after a period of time. In our case, we plan to observe the same clinical team using the same tool and survey questions on multiple occasions. Results from those studies showed the level of reliability of our data set. If the researcher obtains the same results on the two administrations of the instrument, then the reliability coefficient was 1.00. Normally, the correlation of measurements across time would be less than perfect due to different experiences and attitudes that respondents have encountered from the time of the first test [50]. After sorting and processing data collected, a statistical tool, SPSS, was used to further analyze data. We are interested in finding out root-cause effect relationship between factors and communication errors therefore; we plan to use categorical analysis algorithms, such as multinomial regression, to draw relationships between multiple variables. This research utilized statistical methods rather than data mining since this research is hypothesis driven. Nevertheless, data mining approaches can be utilized when a large data repository is established.

3.11 Data Coding

During data collection period, data captured transformed from the paper-based checklist into electronic format through the utilization of a database system (see Appendix). The Database schema shown in figure 4, consisting of 9 tables, is designed to capture all the data from the ICU study into one repository that facilitated further analysis. LP demographic information is stored in its separate entity. Each day at the ICU is treated as a unique study; each study has two tables associated to it, one to collect data from the observation and another table for survey results. The complexity of data captured during observation generated four weak entities associated to the observation table. One of the tables holds the information to identify which observer made the corresponding observations. The other tables store qualitative information about human, technology, and computer interruptions.

Data vary between quantitative and qualitative variables. For that reason, during coding, quantitative variables such as verbal and non-verbal feedback were coded into frequencies. As for qualitative variables, they were coded into numbers that represent each category. For example, for interruptions caused by side conversations among other clinicians, if the LP rejects the interruption then a 1 is recorded at variable “SideConvR” in the table, if accepted then value 1 is recorded in the “SidceConvA” variable. Moving on to the survey questions, since the likert scale is utilized as answers to the questions, answers on the scale were converted into a scale from 1 to 5, 1 being disagree and 5 being agree. Questions 2 and 3 have two parts to them, if the answer to the first question is yes then; there is an additional question to be answered. So, if the first part of the question was answered “no”, then a 0 is recorded, if the answer was “yes” then, the answer depended on the choice of the likert scale. Finally, the last question in the survey is open-ended, so, it was not be included in the coded process however; answers to these questions were used to draw deductions and analysis to what factors affect communication. The number of observations depends on the number of patients admitted to the ICU, for each patient visit there are two checklists used by both observers. During data coding, the plan is to stack all checklists based on the date, then couple the checklists from each patient visit together. The total tallies for each variable on each checklist sheet are counted and checklists are separately recorded in the database.

3.12 Statistical Analysis

Post data coding, the plan moving forward is to utilize various statistical methods to draw correlations and relationships between variables. The first step in this process is to classify our variables. This research treated all variables in the observational checklist tool as predictors to our statistical methods and the survey results served as outcome measures. The reasoning behind this decision is because results from the survey questions serve as a baseline to the results from the observational tool, in other words, the survey questions assessed the communication performance based on the data captured through observation. Based on Biostatistician advice, we have reached an understanding that in order to test our hypothesis, we utilized the following statistical methods:

- Bivariate Correlation
- General Linear Model (GLM)
- Ordinal Regression Model

Moreover, we believe that our initial statistical analysis consisted of multiple regressions and then one-way ANOVAs to account for Roles, all to be run separately on each of the three dependent variables. We may, then, move to general linear mixed model approach to model with more complexity, and also, then, based on statistician input, shift our unit of interest to lead physician and then treat the patient meetings as repeated measures, which could yield interesting results. Although we would like to have a Power $(1-\beta) = .8$, the U.S. federal minimum, and an $\alpha = 0.05$, because it is a new area of inquiry, there is no known delta Δ in the literature upon which we can base power calculations. We had to look at our data results to determine minimum detectable differences in means between the dependent and all independent variables. At that time we will use the Lenth software to calculate our matrix of power [93].

3.13 Post Analysis Approach

After statistically analyzing the data, this research simultaneously moved forward in two directions. The first direction focuses on validating and testing the clinical communication model that was initially proposed. Each factor in the model has to be supported by one incident from literature data or from first hand data, with the emphasis that factors with more incidents are more influential on the communication process. Moreover, model validation goes beyond validating current factors; the plan is to develop finer levels of information representation that reduced redundancy or overlapping of clinical communication factors. Currently, some factors maybe include several communication behaviors and through captured data, those factors can be further broken down into finer levels with accurate sub factors. Through further validation of this model, we aim to build an educational tool that targets clinicians and offers information about the communication framework among the clinical team. We envisage that this tool provided information about key players in the team, safe communication practices, ways to communicate, and high risk communication practices. This tool will be web-based to increase usability and will be promoted for use among clinicians at the ICU at the University of Missouri Hospital and futuristically, introduce the tool to larger audience. We aim to start a new study to assess the usability and effectiveness of the tool among clinicians; we are interested to know if the information portrayed has increased awareness and evolved communication amongst them.

Moving on to the other direction, the ultimate goal of this research is to go beyond the theoretical level into a more practical substance. For that reason, we aim to utilize the clinical communication taxonomy, proposed by Gong et al [94], as well as the communication model to build a clinical communication ontology that as far as we know has not be built yet. This core informatics work, once validated, will serve as a fundamental foundation for future communication research in health care and other industries as well. Based on its knowledge expression capabilities, ontology will play an important role in the data processing plan. Ontology handles information between general categories and specific cases by defining relationships and hierarchies. This facilitates the description and mapping of information from general domains to the particular tasks, which assists knowledge representation. An important feature of ontology processing is its visualization characteristics. Relations between concepts can be visualized to facilitate the educational mission aimed at clinicians.

In order to design a clinical communication ontology that can serve as an educational tool or part of a medical error reporting system, we plan to break down the ontology into two main divisions H-H and H-C interactions. Under each division there will be subdivisions that will follow the clinical communication model, those subdivisions aim at organizing communication factors under common categories while maintaining independencies and exhaustiveness among factors. We realize that the data collected from the observational study at the ICU does not capture all the data mentioned in our model, the reason for that being the complexity and intensity of capturing all those variables during the same time period. For that reason, a focus group study is scheduled to take place after the observational study to capture new variables. Moreover, this research is an effort that will continue to grow as more studies are done and new data is captured, which means that the communication ontology is an evolving outcome of this research.

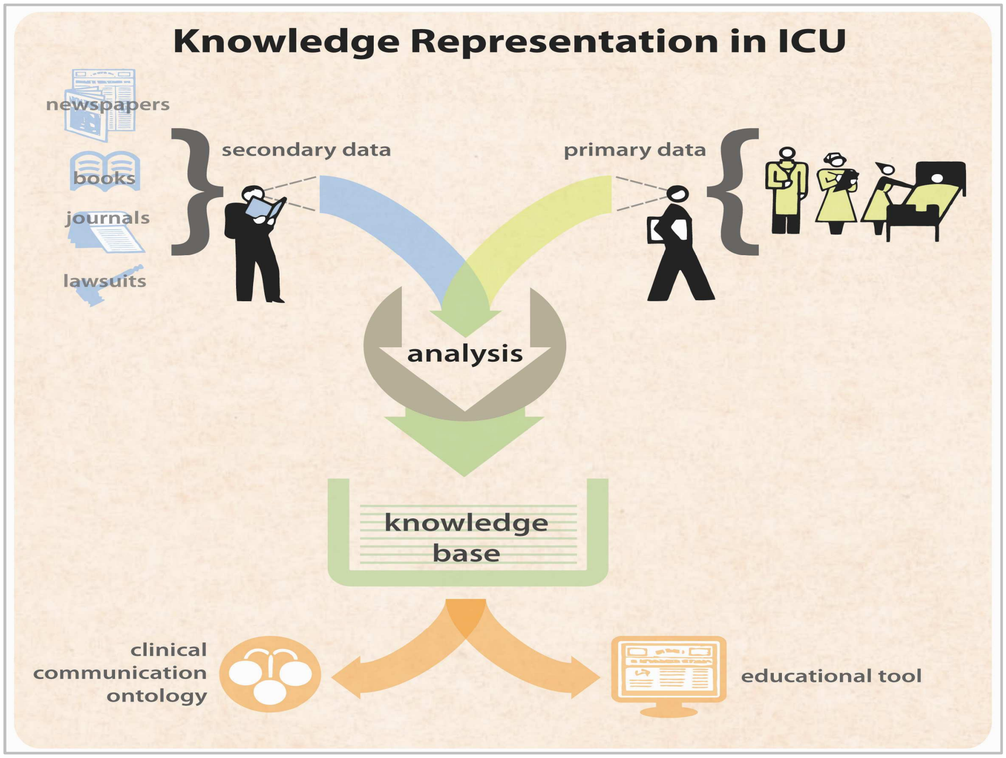


Figure 13 The clinical communication research roadmap

3.14 Observational tool Validation

Since the evaluation of Attending Physician communication patterns has not been extensively researched, there is a need to develop a new tool rather than reuse or modify existing tools. We developed a new observational study that focuses on capturing clinical communication data that served as basis to the analysis of our specific aims. However, given that this is the first instrument, we predicted that there would be minor changes introduced to the instrument by eliminating, modifying and adding factors.

Prior to the beginning of the study, we plan to include expert validity as a part of our content validity process. Expert validity is the process of obtaining the feedback from domain experts on the tool by going through two content validity cycles at: (1) the instrumental level, (2) the item level [95]. Prior to beginning the study, the measurement tools were provided for domain experts to evaluate the instrument at whole by evaluating if the intended target can be met by the scope of the tool. Also, the domain expert rated each item of the instrument on a scale from 1 to 5 (1: not recommended for use, 5: highly recommended). Items not recommended by the expert eliminated from the tools to ensure higher validity levels. Also, experts were asked to make suggestions to new items that if included in the tool can assist our research reach its goal by collecting the correct set of data.

Moreover, during the observational study we constantly assessed the measurement tool. Through collecting first hand data through direct observations, the quality of captured data will increase the level of validity and reliability of our measurement tool [96]. It is reported that the best approach to increase validity and is to use more than one observer, for that reason we plan to utilize two observers to conduct this study [97]. The observers participated in the same clinical activities, use the same tools, however, they conducted the observations at different times. At the initial stages, our measurement tool is expected to further develop based on feedbacks obtains from lead physicians after each session [98]. We developed a set of interview questions that aim at getting a better understanding of communication behavior that might not be captured during the observation. Interview results were compared with results from the observation to assess the level of accuracy and reliability of the tool we are using.

CHAPTER 4 - RESULTS

The ICU clinical team was shadowed for 6 weeks, approximately 55 hours, and during that period the study focused on 6 main communication categories. Those categories capture most important communication events that occurred during patient rounds; table 2 shows the breakdown of communication activities by the communicators, types of interruptions, and computer interactions. Communication from the Attending physician had the highest rate of frequency with 13 instances per patient visits. These types of communication from the Attending physician included teaching statements, requesting new tasks, inquiring about patient status, and providing information that new team members were not aware of. The second most frequent activity during rounds was feedback given from the Attending physician. The Attending physicians constantly provided verbal and non-verbal feedback to the person communicating, which showed statistically significant impact on the team's awareness and satisfaction levels, with a mean of 4.3 out of 5. Next, the clinical team showed a significant information exchange rate with the Attending. We found an association between the frequency of information given by the clinical team and how the team rated their participation and satisfaction levels.

Table 13 Frequency of clinical communication events

Communication Activity	Total Frequency	Average frequency per study session (n=18)	Average frequency per patient visit (n=279)
Patient information conveyed to Attending Physician	1571	87.28	5.63
Feedback given by Attending Physician	2041	113.39	7.31

Communication events done by Attending Physician	3658	203.22	13.11
Interruptions caused by clinicians	844	46.70	3.03
Interruptions caused by technology-aided devices	342	19.00	1.23
Attending-Computer interaction	318	17.67	1.14

Furthermore, we captured the frequency of interruptions that occurred during rounds. We categorize the types of interruption into two categories: (1) clinician-related interruptions, and (2) technology-aided devices interruptions. We found that both types of interruptions occurred in almost all patient visits however, interruptions caused by clinicians occurred approximately 3 times during a patient visit while interruptions from technological devices occurred only once.

4.1 Clinician-Clinician Communication

While interacting, clinicians constantly exchange information and knowledge; this rather complicated process involves two or more communicators, communication factors, and communication events. A communicator is a clinician who interacts with other clinicians by sending or receiving clinical information. Communication factors refer to tacit and explicit knowledge that affect the way a communicator formulates or interprets a message. Communication activities represent clinician's behaviors and technological instances that have an impact on communication. Figure 1 represents the clinician-clinician communication model where a clinician communicates with one or more fellow clinicians. The model shows communication factors and activities that were reported in literature and were observed during the observational study.

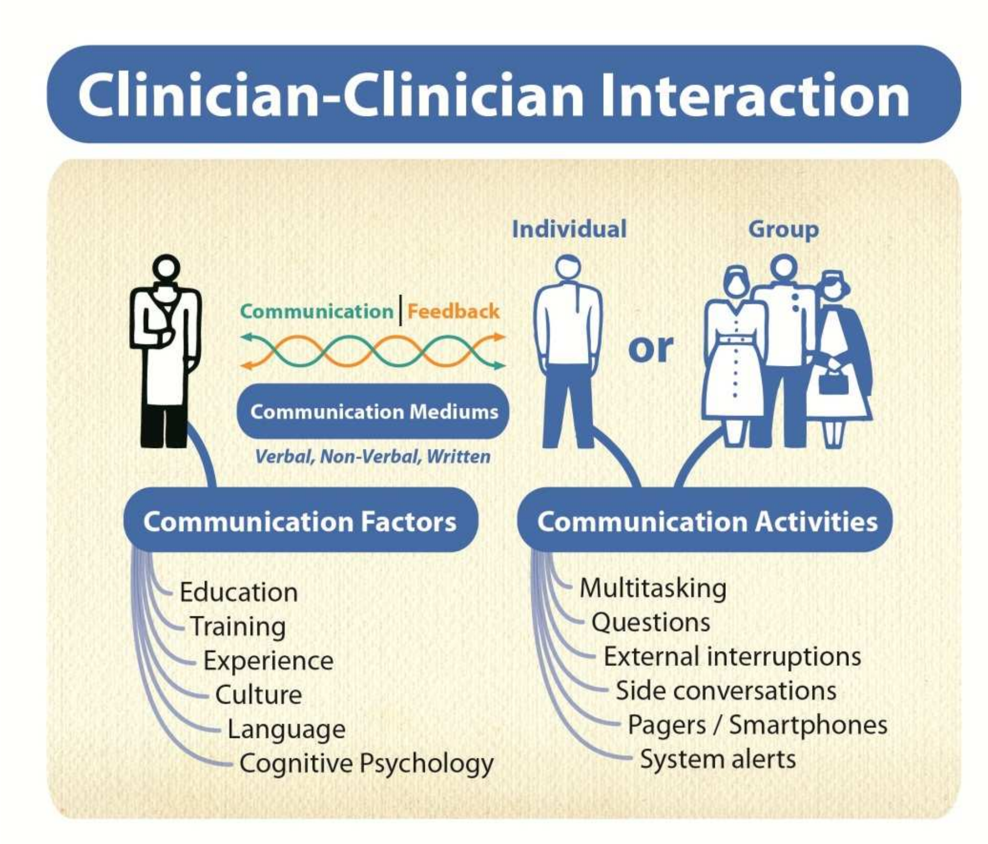


Figure 14 Clinical communication model with an emphasis on Clinician-Clinician interaction.

The communication factors form a knowledge base that shapes the way a clinician interacts with peers. Continuing our work towards further understanding factors that impact communication [15], there are six communication factors that are responsible for how a clinician creates and perceives a message. The level of education and training, and the years of experience a clinician acquired are considered essential factors in the way clinicians exchange information. The previously mentioned factors, when at similar levels, facilitate inter and intra-communication among clinicians since with more education and experience clinicians self-learn how to effectively communicate with their peers.

Considering a clinician's culture is key to reaching high levels of communication effectiveness. Initially, we referred to culture as the background and tradition of a clinician. For example, in some international cultures to agree to a statement the person shakes their head sideways; while in the U.S., a person nods their head to indicate acceptance or agreement. Based on experience, we added a new dimension to the definition of culture, which is the variance in clinical backgrounds and practices among clinical specialties. Finally, we have observed that the overwhelming flow of information and knowledge combined with long working shifts can cause an incorrect recall of events or information. For that reason, cognitive psychology plays an important role during clinician-clinician interaction.

Moving on to communication activities that occur during patient visits at the ICU, we have observed the occurrence of 6 main activities. Even though it is not frequent, multitasking by a receiver usually leads to the sender repeating the message, mostly when the sender requests feedback from the receiver. The other activities are considered as interruptions, which we define as the interference to an ongoing conversation resulting in a pause or an end to the conversation. Clinician interruptions occur when a question interrupts the conversation, or if team members who are not participating in the conversation engage in a side conversation. External interruptions refer to questions or statements from non-clinicians, such as a patient's family. During patient rounds, pagers and system alerts constituted most interruptions in the technology-aided devices category;

nevertheless, their benefits cannot be understated towards patient safety and clinical workflow.

4.2 Clinician-Computer Interaction

Computer interactions are an undivided part of the overall communication process. The utilization of computer systems is clearly present in each patient visitation, figure 2 represents the ICU Clinician-Computer Interaction; the model discussed clinical communication from two perspectives, the clinician and computer. During our observation, we summarized the usability of clinicians to computer systems into storing and retrieving patient information, request new tasks, viewing various types of imaging. In order for a clinician to effectively interact with a computer system, the clinician must receive adequate system training. We define adequate training as the level of which a clinician can fully and correctly use the available system functionalities. Clinicians should be able to navigate the system efficiently by finding the intended information in the shortest and quickest route. Moreover, different clinical systems provide different data interpretations, and clinicians should be able to correctly interpret those formats in a way that is least confusing. Through an effective training, the cognitive gap between system capability and users' expectation should be minimized. Furthermore, in the case of unusual system behavior, it is necessary that clinicians provide problem solving skills. For instance, in the case of error alerts to users, clinicians avoid delays by working around minor or temporary errors either through the system or in person. Also, in the rare instance of fatal errors, such as computer crashing, clinicians should have problem solving skills that would provide an alternate solution to the situation until the system is up again.

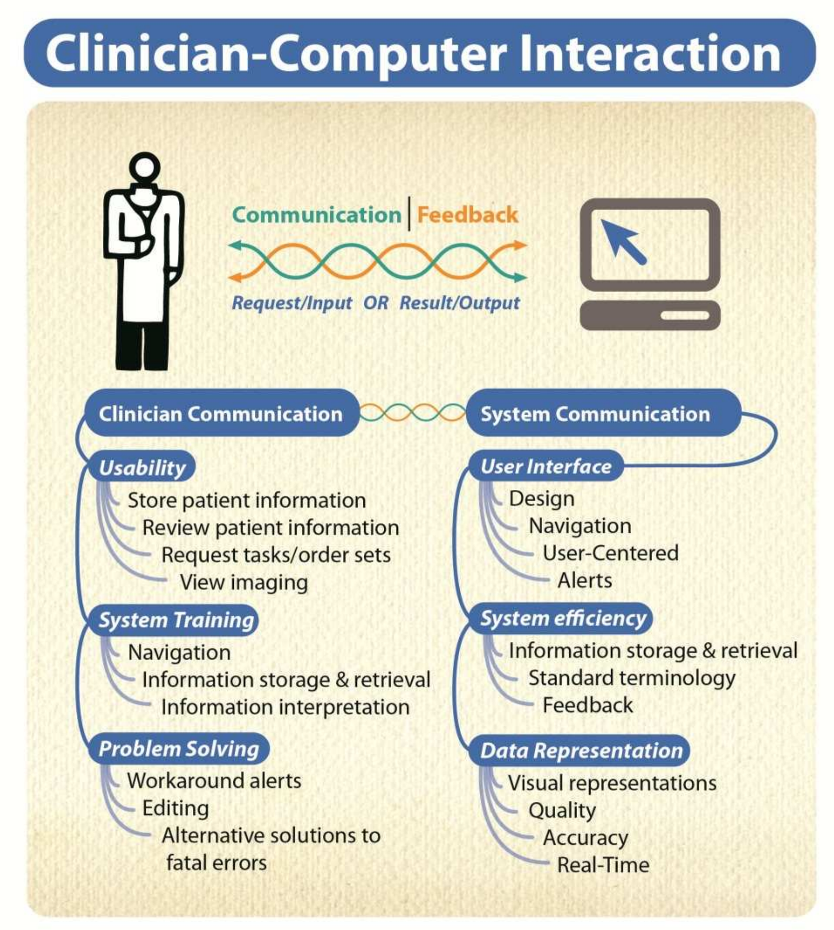


Figure 15 Clinical communication model with an emphasis on Clinician-Computer interaction

On the other hand, implementing a computer system in the ICU should focus on three main areas: (1) graphical user interface, (2) efficiency, (3) data representation. A user friendly interface can be reached through simple design and consistent navigation. Clinician's opinion on the interface must be fully considered when developing the system, their opinion on the design and navigation is important; however, their similarly important opinion on the functionality and effectiveness must not be left out. Furthermore, an efficient data storing and retrieving process that is error-free and easy to use is evident in critical units. Due to the labor intensive environment, clinicians are more susceptible to typos while requesting a patient's medical record; hence, system feedback is an essential error-checking procedure prior to executing a command. Also, standard terminology throughout the system is necessary to avoid inconsistencies and confusion. Finally, meaningful and reliable data representation is necessary for effective clinician-computer interaction. Visual representations are easier to read and interpret than many numeric values. Also, it is necessary for the system to represent real-time, accurate patient data, and high imaging quality.

4.3 Statistical Analysis

There are two sets of variables used in this research, the first set of variables come from the observational study and the second from the post-observation survey. Throughout the analysis we used acronyms for each variable, therefore table 14 describes each acronym used in our analysis. There are 28 variables used in the observation study and 4 variables used for survey questions. Two separate analyses were done on each set of variables then combined analyses were done on both sets together.

Table 14 Table define each variable name used in the observational study

Variable Name	Description
infotolp	Information conveyed to Attending Physician
verbal	Verbal feedback by Attending
nonverba	Non-verbal feedback by Attending
repititi	Repetitions by Attending
giveinfo	Information provided by Attending
requesti	Attending requesting patient information
requestn	Attending requesting new task
teaching	Attending teaching

relat_y	Questions related to topic of discussion and accepted by Attending
relat_n	Questions related to topic of discussion and rejected by Attending
unrlat_y	Questions unrelated to topic of discussion and accepted by Attending
unrlat_n	Questions unrelated to topic of discussion and rejected by Attending
sid_y	Side conversations occurring during communication and accepted by Attending
sid_n	Side conversations occurring during communication and rejected by Attending
ext_y	External interruptions occurring during communication and accepted by Attending
ext_n	External interruptions occurring during communication and rejected by Attending
aler_y	Computer alerts occurring during communication and accepted by Attending
aler_n	Computer alerts occurring during communication and rejected by Attending
pag_y	Pagers occurring during communication and accepted by Attending
pag_n	Pagers occurring during communication and rejected by Attending
tel_y	Cell phones occurring during communication and accepted by Attending
tel_n	Cell phones occurring during communication and rejected by Attending
mis1	Attending fixing their own mistakes
mis2	Attending correcting other member's mistakes
readinfo	Attending viewing patient information
readxray	Attending viewing imaging
keyboard	Attending using keyboard to enter data
mouse	Attending using mouse to navigate

Initially, the 28 variables from the observation study were analyzed using descriptive analysis tests to understand the range of variables, the average for each variable, the minimum and maximum values, and the standard deviation for each variable. Table 15 shows the summary for the descriptive analysis for the observation variables, for most variables, there were incidents were those variables did not occur in a given observation. The Attending requesting tasks to be done or completed was variable with the most number of frequencies in a given observation followed by the attending requesting patient information, and information conveyed to the Attending physician. The least frequent variable in a given observation were unrelated interruptive questions and mistakes made by the Attending and corrected by the Attending. The variable with the highest mean per patient visit was “requesti”, which shows that most communication made aimed at requesting patient information. Similarly, “requesti” and “infotolp” had the highest standard deviation among the variables which shows the high variance in those variables which could be a result of the day of the week or variances between one attending and the other. For each variable, a more detailed descriptive analysis test was conducted, which the results off are available in the Appendix section.

Table 16 Descriptive analysis of all variables used in the observational study

Descriptive Analysis					
Variable Name	N	Minimum	Maximum	Mean	Std. Deviation
infotolp	279	1	20	5.63	3.460
verbal	279	0	13	3.85	2.437
nonverba	279	0	15	3.47	2.997
repititi	279	0	5	.88	1.069
giveinfo	279	0	8	1.25	1.321
requesti	279	0	23	5.72	3.804
requestn	279	0	20	3.57	2.426
teaching	279	0	16	2.57	2.754

relat_y	279	0	7	.97	1.216
relat_n	279	0	2	.04	.220
unrlat_y	279	0	1	.05	.226
unrlat_n	279	0	1	.00	.060
sid_y	279	0	2	.10	.324
sid_n	279	0	11	1.61	1.749
ext_y	279	0	6	.22	.752
ext_n	279	0	2	.03	.178
aler_y	279	0	4	.14	.481
aler_n	279	0	20	.62	1.711
pag_y	279	0	2	.11	.358
pag_n	279	0	2	.09	.298
tel_y	279	0	2	.09	.310
tel_n	279	0	3	.18	.434
mis1	279	0	1	.01	.119
mis2	279	0	2	.07	.297
readinfo	279	0	6	.91	1.173
readxray	279	0	2	.11	.358
keyboard	279	0	3	.02	.207
mouse	279	0	7	.10	.613

After analyzing each variable, the next step was to conduct analysis of variance among observation variables by clustering the data into three main groups: (1) Attending physicians, (2) Day of the week, (3) Size of the clinical team. Kruskal-Wallis non-parametric test was used to do one-way analysis of variance by ranks. The following tables show the results of the analyses.

Table 15 Table showing the results of Kruskal-Wallis test with Attending physician as the rank

LPID	N	Mean Rank

VERBAL	1	88	147.31
	2	99	121.83
	3	92	152.55
	Total	279	
NONVERBA	1	88	150.51
	2	99	141.12
	3	92	128.74
	Total	279	
REPITITI	1	88	155.95
	2	99	119.14
	3	92	147.19
	Total	279	
GIVEINFO	1	88	144.91
	2	99	133.42
	3	92	142.38
	Total	279	
REQUESTI	1	88	129.54
	2	99	114.48
	3	92	177.47
	Total	279	
REQUESTN	1	88	171.25
	2	99	90.70
	3	92	163.16
	Total	279	
TEACHING	1	88	163.69
	2	99	112.40
	3	92	147.04
	Total	279	
MIS1	1	88	141.17
	2	99	139.41
	3	92	139.52
	Total	279	
MIS2	1	88	142.48
	2	99	140.04
	3	92	137.59
	Total	279	
READINFO	1	88	109.50
	2	99	133.45
	3	92	176.22
	Total	279	
READXRAY	1	88	156.65
	2	99	132.06
	3	92	132.63
	Total	279	
KEYBOARD	1	88	139.58

	2	99	140.83
	3	92	139.51
	Total	279	
MOUSE	1	88	142.38
	2	99	140.18
	3	92	137.53
	Total	279	

Table 15 show the frequency and mean value for each observation variable for each Attending physician. Even though each Attending physician was observed for 6 days, there was some variation between each physician when it came to the number of patients visited; this suggests that the mean per patient visit will be a better measure. For some variables, there are differences in mean value between the Attending physicians, for that reason why conducted a Chi-Square test to identify which variables were significantly different among the physicians. We used a 95% confidence interval where for a variable to be significant different alpha has to be less than or equal to 0.05 (5%). Table 16 show the results for test statistic, 7 variables were significantly different between the physicians, they are: verbal feedback, repetitions, request patient information, request new task, teaching, read patient information, read imaging. These variables show that the Attending physicians had similar communication activity in 6 variables and they exercised different communication activities in the 7 variables aforementioned.

Table 16 Test statistics of observation variables based on Attending physician

	VERBAL	NONVERBA	REPITITI	GIVE INFO	REQ. INFO	REQ. NEW TASK	TEACHING
Chi-Square	8.129	3.362	12.497	1.157	31.501	58.952	20.509
df		2	2	2	2	2	2

Asymp. Sig.	**.017**	.186	**.002**	.561	**.000**	**.000**	**.000**

	MIS1	MIS2	READINFO	READXRAY	KEYBOARD	MOUSE
Chi-Square	.640	.960	36.748	20.851	.382	1.435
df	2	2	2	2	2	2
Asymp. Sig.	.726	.619	**.000**	**.000**	.826	.488

a Kruskal Wallis Test
b Grouping Variable: LPID

One of the hypotheses of this research is to test if communication behaviors change based on the day of the week, in other words, is there a significant difference in communication loads on weekdays and weekends. Table 17 shows the frequency and mean rank for all observation variables using day type as the rank. The number of patients visited on weekdays was 173 compared to 106 on weekends, even though it is expected to visit the same number of patients on weekdays and weekends, however, the rigorous admission and discharge process might have a role on this significant variance.

Table 17 Table showing the results of Kruskal-Wallis test with Day type as the rank

	DAY_TYP	N	Mean Rank
VERBAL	week day	173	147.87
	week end	106	127.16
	Total	279	
NONVERBA	week day	173	147.91
	week end	106	127.09
	Total	279	
REPITITI	week day	173	144.67
	week end	106	132.37
	Total	279	

GIVEINFO	week day	173	148.02
	week end	106	126.92
	Total	279	
REQUESTI	week day	173	146.32
	week end	106	129.69
	Total	279	
REQUESTN	week day	173	147.00
	week end	106	128.57
	Total	279	
TEACHING	week day	173	150.69
	week end	106	122.56
	Total	279	
MIS1	week day	173	139.61
	week end	106	140.63
	Total	279	
MIS2	week day	173	141.12
	week end	106	138.17
	Total	279	
READINFO	week day	173	125.25
	week end	106	164.07
	Total	279	
READXRAY	week day	173	132.14
	week end	106	152.83
	Total	279	
KEYBOARD	week day	173	140.42
	week end	106	139.31
	Total	279	
MOUSE	week day	173	137.73
	week end	106	143.71
	Total	279	

In order to identify which variables had significant differences between weekdays and weekends, a Chi-Square test was conducted and the results are shown in Table 18.

We used mean rank to avoid calculating the mean value for each patient visit for both day types, that way the difference in patient visit can be eliminated by calculating the average per visit for each day type. Six variables showed significant differences between the both day types: information conveyed to the Attending, verbal feedback, nonverbal feedback, Attending physician provides information to the team, teaching, external interruptions, side conversations, read patient information from electronic medical record, view patient electronic imaging.

Table 18 Test statistics of observation variables based on Day type

Day \ Outcome variable	infotolp	verbal	nonverba	repititi	Give info	Request info	Request new task	teaching
Weekdays	5 (4-8)	3 (2-6)	1 (1-5)	1(0-1)	1 (0-2)	5 (3-8)	4 (2-5)	2 (1-5)
Weekend days	4 (2-6)	2 (3-8)	2 (1-4)	0(0-1)	1 (0-2)	5 (3-8)	3 (2-5)	1 (0-3)
Asymp. Sig. (2-tailed)	.005	.036	.035	.183	.027	.093	.061	.004

Day	Related	Unrelated	side_conv	external	alerts	pager	telephone	mis1	mis2
Weekdays	1 (0-2)	0 (0-0)	2 (0-3)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Weekend days	0 (0-1)	0 (0-0)	1 (0-2)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Asymp. Sig. (2-tailed)	.003	.365	.000	.183	.073	.286	.395	.619	.474

Day	Readinfo	Read Xray	Keyboard	Mouse
Weekdays	0 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)
Weekend days	1 (0-2)	0 (0-0)	0 (0-0)	0 (0-0)
Asymp. Sig. (2-tailed)	0.00	0.00	0.588	0.074

a. Grouping Variable: day_typ
b. P-values are based on Mann-Whitney test
c. The data represents the median of each observation variable, the values in the parenthesis represent the Interquartile ranges

Another hypothesis of interest was if the size of the clinical team on rounds affects the frequency of communication and if it does which variables show significant differences when the team size changes. We categorized the team size to “small” and “large”. Small size team consist of 8 or less, the justification to this number is that the majority of rounds the team consisted of the Attending physician, a fellow, 2 residents (at least), 1 nurse (at least), 2 medical student (at least). Therefore, the size of the team can vary from 6-8 members and that is considered “small” size team. Large size teams would include 9 or more clinical team members. The largest team size during the study consisted of 18 team members while the smallest team consisted of 5 team members. From the 279 patient visits, 154 visits had small team size and 125 visits had large team size, there is no huge difference which provides a good distribution for the data.

Table 19 Table showing the results of Kruskal-Wallis test with Team size as the rank

	team_c	N	Mean Rank
infotolp	small	154	125.88
	large	125	157.40
	Total	279	
verbal	small	154	128.80
	large	125	153.80
	Total	279	
nonverba	small	154	127.33
	large	125	155.61

	Total	279	
repititi	small	154	137.95
	large	125	142.52
	Total	279	
giveinfo	small	154	130.27
	large	125	151.98
	Total	279	
requesti	small	154	139.28
	large	125	140.89
	Total	279	
requestn	small	154	140.31
	large	125	139.61
	Total	279	
teaching	small	154	137.29
	large	125	143.34
	Total	279	
relat_y	small	154	129.61
	large	125	152.80
	Total	279	
relat_n	small	154	139.92
	large	125	140.10
	Total	279	
unrlat_y	small	154	137.94
	large	125	142.54
	Total	279	
unrlat_n	small	154	140.41

	large	125	139.50
	Total	279	
sid_y	small	154	141.56
	large	125	138.08
	Total	279	
sid_n	small	154	114.79
	large	125	171.06
	Total	279	
ext_y	small	154	137.99
	large	125	142.47
	Total	279	
ext_n	small	154	139.71
	large	125	140.36
	Total	279	
aler_y	small	154	138.49
	large	125	141.86
	Total	279	
aler_n	small	154	133.13
	large	125	148.47
	Total	279	
aler	small	154	133.36
	large	125	148.18
	Total	279	
aler_p	small	46	48.35
	large	48	46.69
	Total	94	

pag_y	small	154	137.39
	large	125	143.22
	Total	279	
pag_n	small	154	138.01
	large	125	142.46
	Total	279	
tel_y	small	154	137.64
	large	125	142.90
	Total	279	
tel_n	small	154	138.21
	large	125	142.20
	Total	279	
mis1	small	154	140.72
	large	125	139.12
	Total	279	
mis2	small	154	142.42
	large	125	137.02
	Total	279	
readinfo	small	154	153.23
	large	125	123.70
	Total	279	
readxray	small	154	146.41
	large	125	132.11
	Total	279	
keyboard	small	154	139.81
	large	125	140.24

	Total	279	
mouse	small	154	142.64
	large	125	136.75
	Total	279	

Table 20 shows the results for the test statistics, from the 13 variables examined, 6 communication variables showed significant differences between small and large size teams, the variables were: the information conveyed to the Attending physician, verbal and nonverbal feedback from the Attending physician, Attending providing information to the team, read electronic patient information, read electronic patient imaging.

Table 20 The Association between small size team and large size teams days for observation variables

Outcome variable / Size	infotolp	verbal	nonverba	repititi	Give info	Req. patient info	Request new task	teachin g
Small	4 (3-6)	3 (2-4)	2 (1-4)	1 (0-1)	1 (0-2)	5 (3-8)	3 (2-5)	2 (1-3)
Large	5 (4-9)	4 (2-6)	3 (1-6)	1 (0-1)	1 (0-2)	5 (3-8)	3 (2-5)	2 (0-5)
Asymp. Sig. (2-tailed)	.001	.009	.003	.613	.02	.868	.942	.527

Outcome variable / Size	side_conv	external	alerts	pagers	telephon e
Small	1 (0-2)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)

Large	2 (1-3)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-1)
Asymp. Sig. (2-tailed)	.000	.582	.068	.257	.242

Outcome variable / Size	mis1	mis2	readinfo	readxray	keyboard	mouse
Small	0 (0-0)	0 (0-0)	1 (0-2)	0 (0-0)	0 (0-0)	0 (0-0)
Large	0 (0-0)	0 (0-0)	0 (0-1)	0 (0-0)	0 (0-0)	0 (0-0)
Asymp. Sig. (2-tailed)	.423	.180	.001	.004	.828	.072

a. Grouping Variable: team_size
b. P-values are based on Mann-Whitney test
c. The data represents the median of each observation variable, the values in the parenthesis represent the Interquartile ranges

4.3.1 Pearson's Correlations

We are interested in finding the level of dependence between the observation variables, in other words, we want to find any correlation, a broad class of statistical relationships between variables. The most familiar methodology to find correlation is Pearson's correlation; it is obtained by dividing the covariance of the two variables by the product of their standard deviations. 14 variables were used to find any relationships or associations between them;

Table 21 shows the results for Pearson's correlation. The result includes two field for each relationship, the first is the Pearson correlation value and the second is the level of significance. If the Pearson correlation value is positive, this means that there is a direct relationship between both variables, which is when one variable increases the other variable increases. If the Pearson correlation value is negative then there is an indirect relationship between the variables, where if one variable increases the other variable decreases. The level of significance is show in the two tailed test field, if the value of the 2-tailed test is < 0.05, then we consider there is significant interaction between the variables, otherwise the relationship between the variables is insignificant. In order to determine how strong or weak the correlation is we use the following distribution, if the correlation value is:

- = +.70 or higher Very strong positive relationship
- +.40 to +.69 Strong positive relationship
- +.30 to +.39 Moderate positive relationship
- +.20 to +.29 weak positive relationship
- +.01 to +.19 No or negligible relationship
- -.01 to -.19 No or negligible relationship
- -.20 to -.29 weak negative relationship
- -.30 to -.39 Moderate negative relationship
- -.40 to -.69 Strong negative relationship
- -.70 or higher Very strong negative relationship

Table 21 Pearson correlation for observation variables

		INFOTOLP	VERBAL	NONVERBA	REPITITI	GIVEINFO	REQUESTI	REQUESTN	TEACHING	MIS1	MIS2	READINFO	READXRAY	KEYBOARD	MOUSE
INFOTOLP	Pearson Cor	1	**.432(**)**	**.451(**)**	.326(**)	.312(**)	**.665(**)**	.329(**)	**.543(**)**	-0.031	0.099	.170(**)	-0.071	0.087	0.027

	relation														
	Sig. (2-tailed)	.	.000	.000	.000	.000	.000	.000	.000	0.609	0.098	0.004	0.235	0.149	0.652
VERBAL	Pearson Correlation	.432(**)	1	.511(**)	.299(**)	.324(**)	.467(**)	.375(**)	.541(**)	0.008	0.01	.181(**)	0.069	0.049	-0.014
	Sig. (2-tailed)	0	0	0	0	0	0	0	0	0.899	0.863	0.002	0.249	0.41	0.815
NONVERBA	Pearson Correlation	.451(**)	.511(**)	1	.235(**)	.314(**)	.381(**)	.235(**)	.543(**)	0.021	.168(**)	.138(*)	0.062	0.013	0.014
	Sig. (2-tailed)	0	0	.	0	0	0	0	0	0.722	0.005	0.021	0.303	0.833	0.812
REPITITI	Pearson Correlation	.326(**)	.299(**)	.235(**)	1	.226(**)	.357(**)	.423(**)	.411(**)	-0.014	-0.006	0.112	0.083	0.093	0.078
	Sig. (2-tailed)	0	0	0	.	0	0	0	0	0.81	0.916	0.062	0.169	0.12	0.191
GIVEINFO	Pearson Correlation	.312(**)	.324(**)	.314(**)	.226(**)	1	.171(**)	.246(**)	.251(**)	.183(**)	0.082	0.11	0.054	0.059	0.023
	Sig. (2-tailed)	0	0	0	0	.	0.004	0	0	0.002	0.174	0.067	0.367	0.326	0.705
REQUESTI	Pearson Correlation	.665(**)	.467(**)	.381(**)	.357(**)	.171(**)	1	.414(**)	.489(**)	0.065	0.104	.362(**)	0.076	0.049	0.026
	Sig. (2-tailed)	0	0	0	0	0.004	.	0	0	0.282	0.083	0	0.205	0.415	0.669
REQUESTN	Pearson Correlation	.329(**)	.375(**)	.235(**)	.423(**)	.246(**)	.414(**)	1	.498(**)	0.071	-0.002	.124(*)	0.043	0.019	0.047
	Sig. (2-	0	0	0	0	0	0	.	0	0.236	0.974	0.038	0.476	0.758	0.43

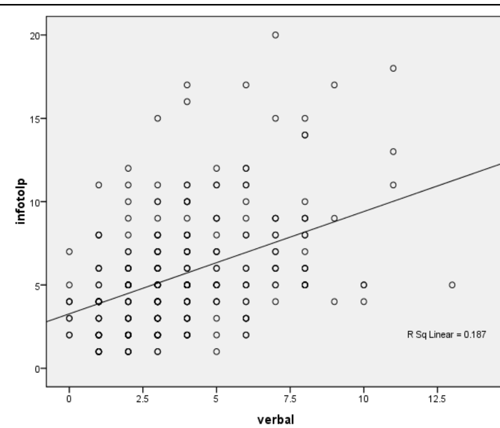
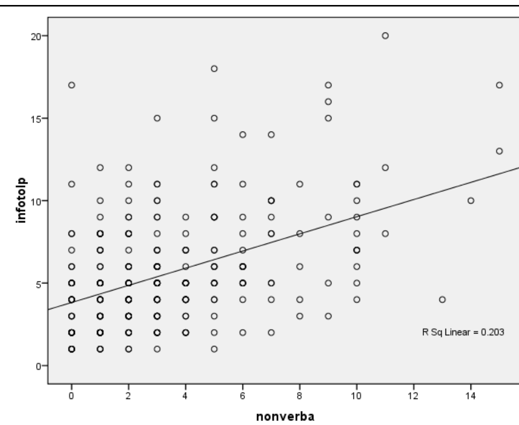
	tailed)														
TEACHING	Pearson Correlation	**.543(**)**	**.541(**)**	**.543(**)**	**.411(**)**	.251(**)	**.489(**)**	**.498(**)**	1	0.008	.130(*)	.203(**)	0.052	0.086	0.059
	Sig. (2-tailed)	**0**	**0**	**0**	**0**	0	**0**	**0**	.	0.895	0.03	0.001	0.384	0.153	0.327
MIS 1	Pearson Correlation	-0.031	0.008	0.021	-0.014	**.183(**)**	0.065	0.071	0.008	1	0.072	-0.042	0.047	-0.013	-0.019
	Sig. (2-tailed)	0.609	0.899	0.722	0.81	**0.002**	0.282	0.236	0.895	.	0.228	0.482	0.435	0.834	0.751
MIS 2	Pearson Correlation	0.099	0.01	**.168(**)**	-0.006	0.082	0.104	-0.002	**.130(*)**	0.072	1	**.153(*)**	-0.041	-0.025	-0.018
	Sig. (2-tailed)	0.098	0.863	**0.005**	0.916	0.174	0.083	0.974	**0.03**	0.228	.	**0.011**	0.491	0.675	0.759
READINFO	Pearson Correlation	.170(**)	.181(**)	.138(*)	0.112	0.11	**.362(**)**	.124(*)	.203(**)	-0.042	.153(*)	1	0.024	0.008	0.022
	Sig. (2-tailed)	0.004	0.002	0.021	0.062	0.067	**0**	0.038	0.001	0.482	0.011	.	0.692	0.894	0.713
READXRAY	Pearson Correlation	-0.071	0.069	0.062	0.083	0.054	0.076	0.043	0.052	0.047	-0.041	0.024	1	.162(**)	.345(**)
	Sig. (2-tailed)	0.235	0.249	0.303	0.169	0.367	0.205	0.476	0.384	0.435	0.491	0.692	.	0.007	0
KEYBOARD	Pearson Correlation	0.087	0.049	0.013	0.093	0.059	0.049	0.019	0.086	-0.013	-0.025	0.008	.162(**)	1	**.665(**)**
	Sig. (2-tailed)	0.149	0.41	0.833	0.12	0.326	0.415	0.758	0.153	0.834	0.675	0.894	0.007	.	**0**
MOUSE	Pearson Cor	0.027	-0.014	0.014	0.078	0.023	0.026	0.047	0.059	-0.019	-0.018	0.022	.345(**)	**.665(**)**	1

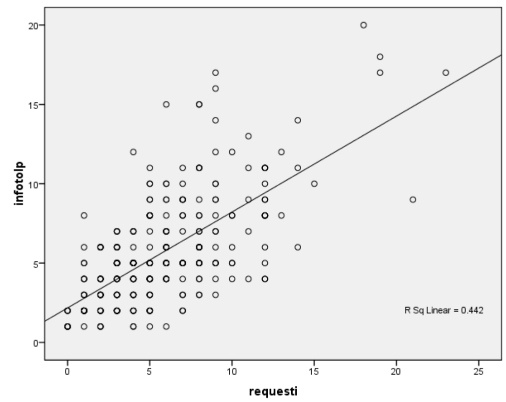
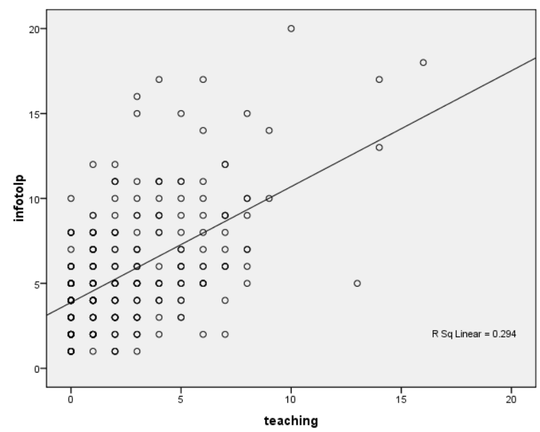
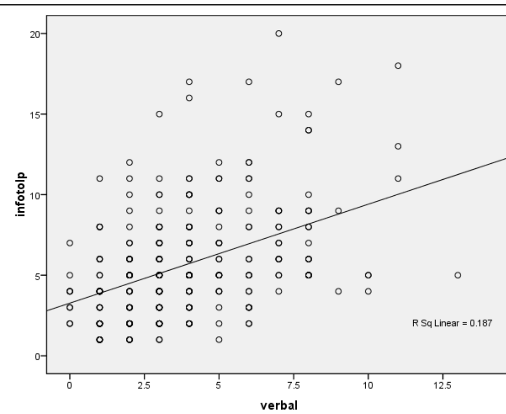
	relation														
	Sig. (2-tailed)	0.652	0.815	0.812	0.191	0.705	0.669	0.43	0.327	0.751	0.759	0.713	0	**0**	.

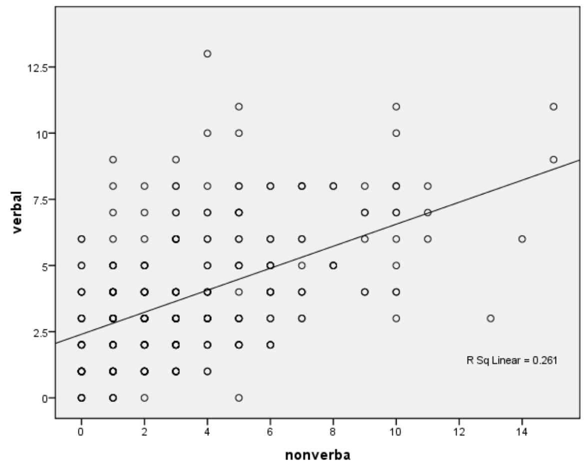
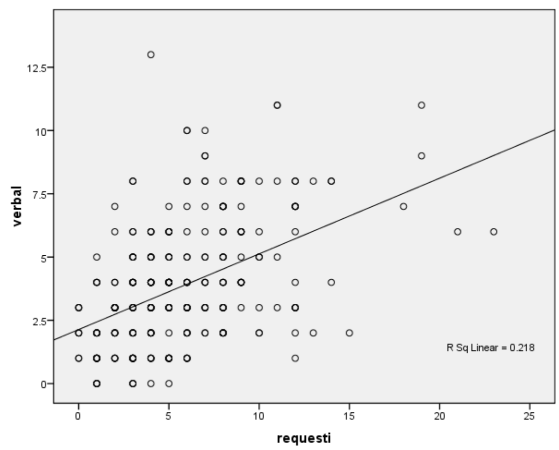
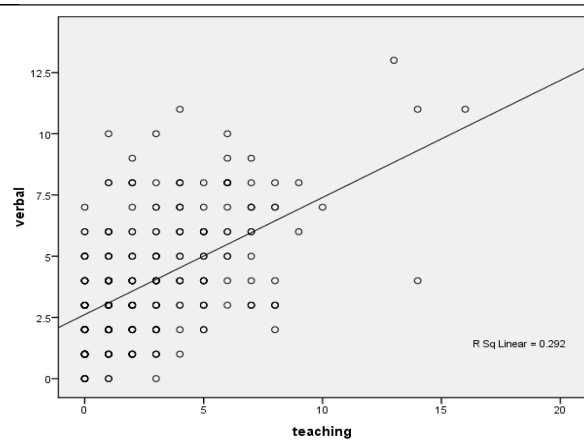
The highlighted fields in

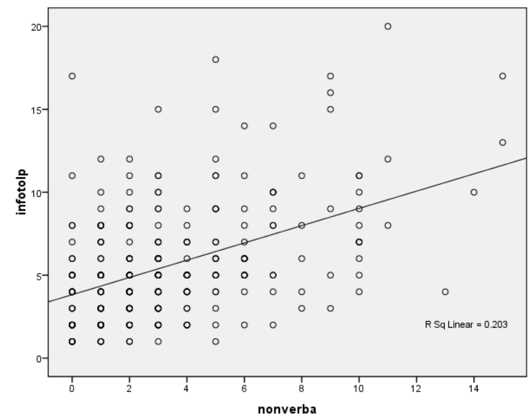
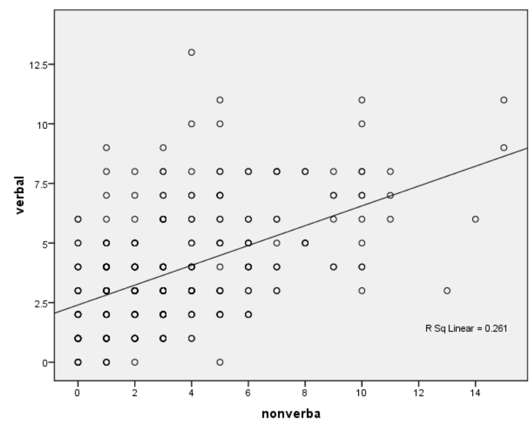
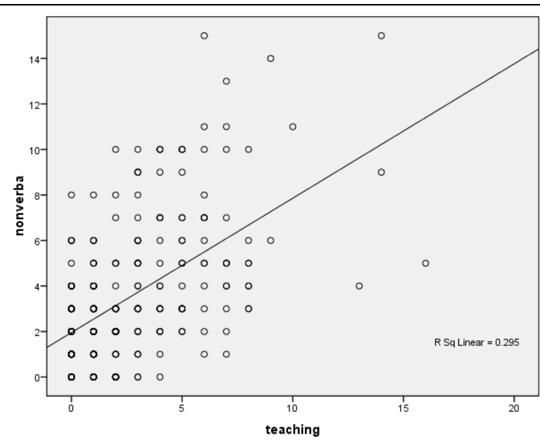
Table 21 show the variables with strong positive relationship, Table 22 shows the graphical representation of the relationship between observation variables.

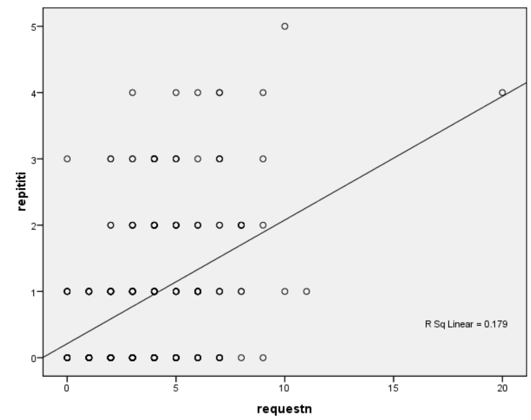
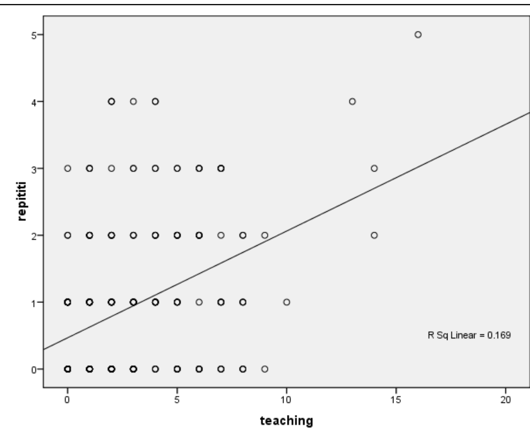
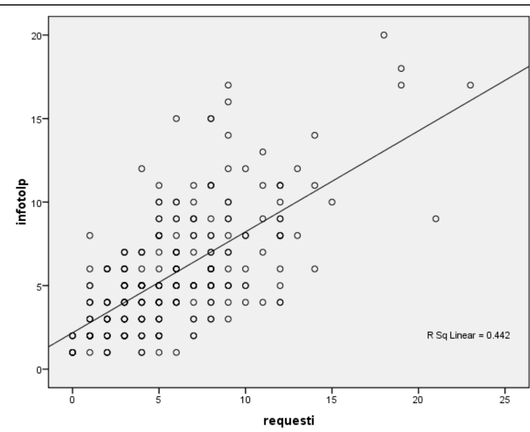
Table 22 Observation variables with strong correlation

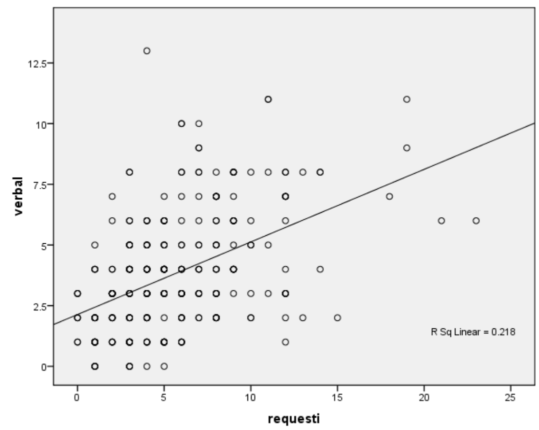
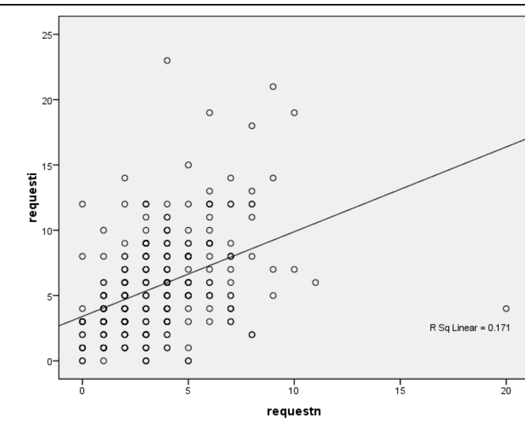
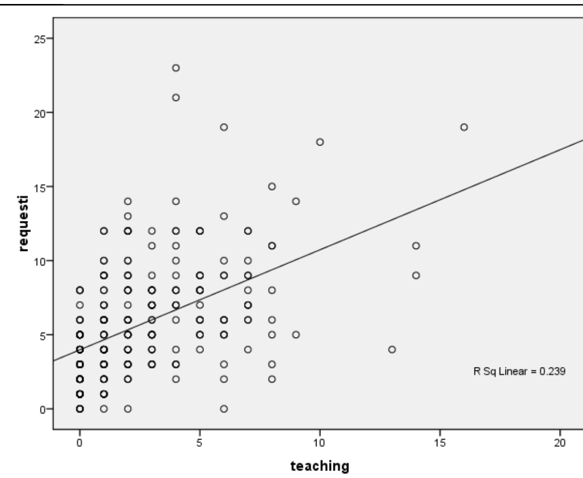
Variable	**Correlated with**	**Scatter plot**
Information to Attending physician	Verbal Feedback	
	Non-verbal feedback	

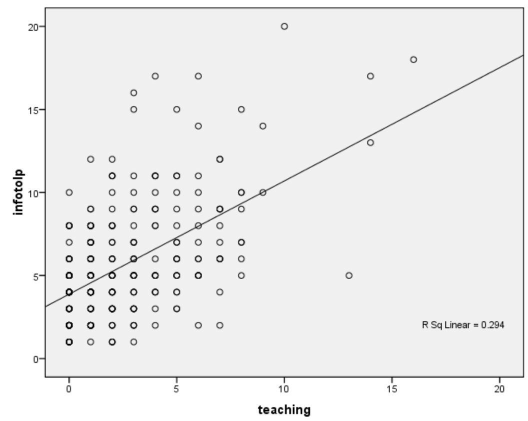
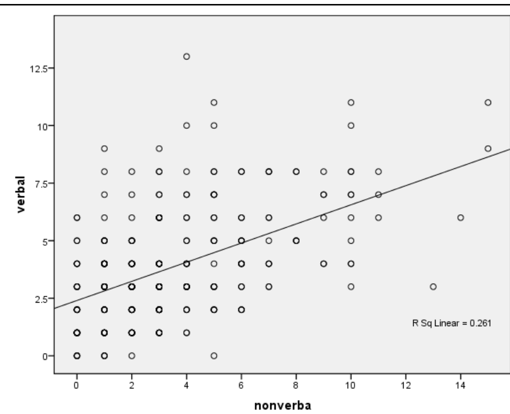
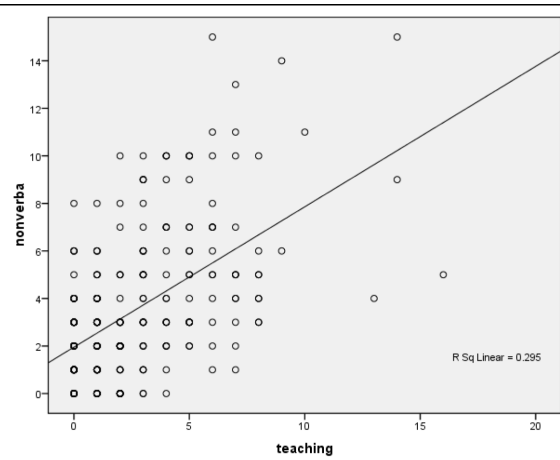
	Request patient information	
	Teaching	
Verbal Feedback	Information to Attending physician	

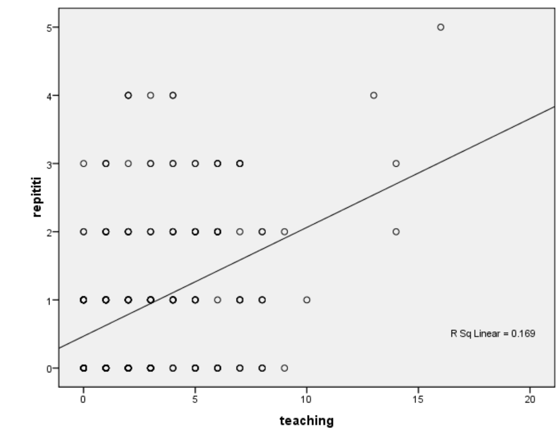
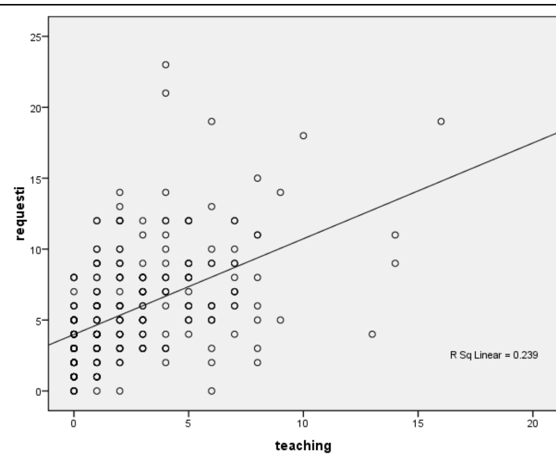
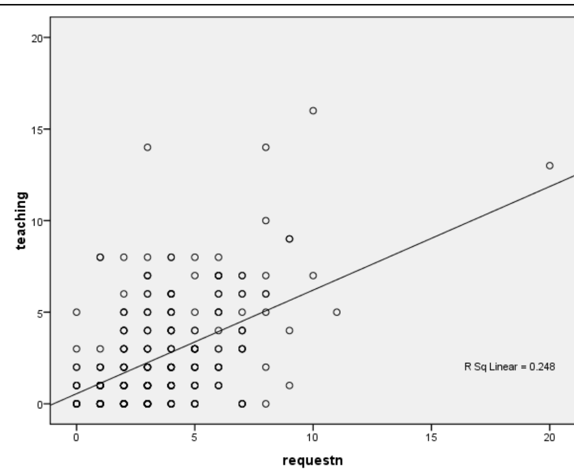
	Non-verbal feedback	
	Request patient information	
	Teaching	

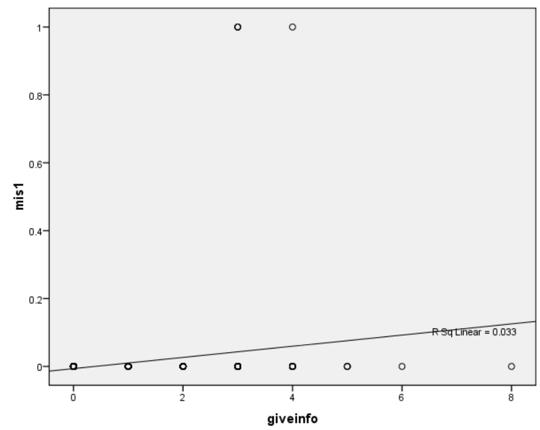
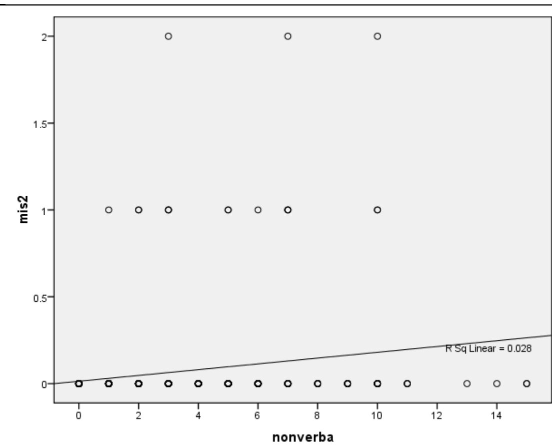
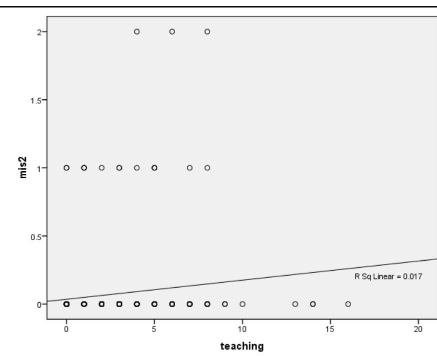
Non-Verbal Feedback	Information to Attending physician	
	Verbal feedback	
	Teaching	

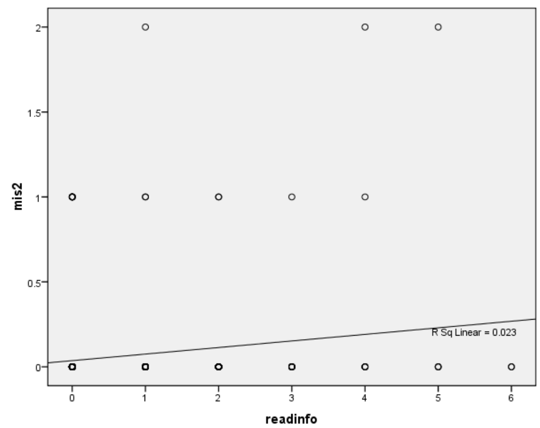
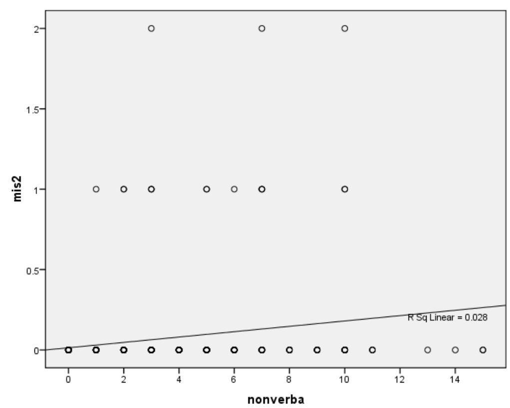
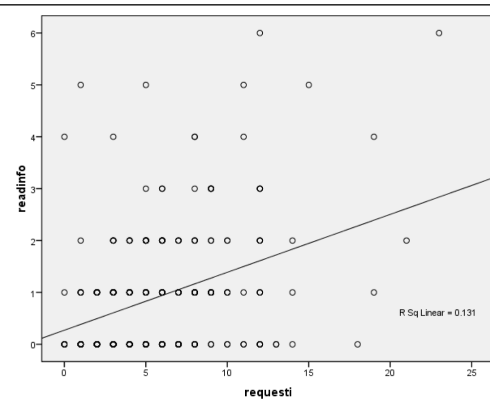
Repetitions	Request New Task	
	Teaching	
Request patient information	Information to Attending physician	

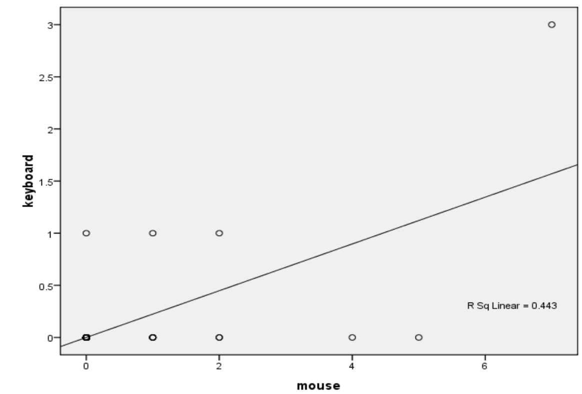
	Verbal feedback	
	Request New Task	
	Teaching	

Teaching	Information to Attending physician	
	Verbal feedback	
	Non-verbal feedback	

	Repetitions	
	Request Patient information	
	Request New Task	

Attending correcting themselves	Give information	
Attending correcting team	Non-verbal feedback	
	Teaching	

	Read information	
	Non-verbal feedback	
Read electronic patient information	Request patient information	

Keyboard	Mouse	

4.3.2 Survey Questions Analysis

Following the same approach with the observation variables, survey results were further analyzed by conducting cross tabulation, which is the process of creating a contingency table from multivariate frequency distribution of statistical variables. The total numbers of surveys are 149, the surveys did not include unique identifiers however, the clinical role for each participant was collected, and there were a total of 22 clinical roles. Table 23 shows each role's identification number that participated in the survey and for each RoleID its corresponding role name.

Table 23 Mapping RoleID with Role names

RoleID	Role Name
1	RN
2	PharmD
3	Fellow
4	Respiratory Therapist
5	Administrator

6	1st year Resident
7	2nd year Resident
8	3rd year Resident
9	3rd year Medical Student
10	4th year Medical Student
11	Pulmonary Fellow
12	Advanced Practice RN
13	Pulmonary Fellow
14	Student Nurse
15	Dietician
16	Nurse Practitioner
17	Physician Assistant
18	4th Resident
19	Pharmacy Resident
20	Graduate Nurse
21	Physical Therapy
22	Unit Clerk

Each survey consisted of 4 main questions following a 5-likert scale design. For each question we were interested to find out the if there are any patterns among the answers of each clinical role Table 24,Table 24,Table 25,Table 26, and Table 27 show the cross tabulation results for questions 1-4 respectively. For survey questions 1 and 4, none of the participants answered the question with answer 2, which is "somewhat ineffective”. Similarly, for question 2 no answers included answer 1,2, or 3, and Question 3 did not include answers 1 and 2.

For question 1 results, most participants (85%) agreed that they are aware of the next treatment for their patients. While 13.6% answered the question with a “somewhat agree” answer, and 1.4% of the participants responded negatively implying their uncertainty of the next treatment for their patients. Most responses targeted good understanding of the daily goals however, dieticians were split between “agree” (57%) and “somewhat agree” (43%) responses making dieticians as the only clinical group with significant variance in their answers when it came to the next treatment for their patients.

Table 24 Crosstabulation between Survey question 1 and clinical roles

			Q1				Total
			1	3	4	5	1
ROLEID	1	Count			5	29	34
		% within ROLEID			14.70%	85.30%	100.00%
	2	Count				4	4
		% within ROLEID				100.00%	100.00%
	3	Count				4	4
		% within ROLEID				100.00%	100.00%
	4	Count	1		3	9	13
		% within ROLEID	7.70%		23.10%	69.20%	100.00%
	6	Count			3	9	12
		% within ROLEID			25.00%	75.00%	100.00%
	7	Count			2	30	32
		% within ROLEID			6.30%	93.80%	100.00%
	8	Count				9	9
		% within ROLEID				100.00%	100.00%
	10	Count			1	12	13

	% within ROLEID			7.70%	92.30%	100.00%
12	Count				2	2
	% within ROLEID				100.00%	100.00%
13	Count				1	1
	% within ROLEID				100.00%	100.00%
14	Count			2	5	7
	% within ROLEID			28.60%	71.40%	100.00%
15	Count			3	4	7
	% within ROLEID			42.90%	57.10%	100.00%
16	Count				1	1
	% within ROLEID				100.00%	100.00%
17	Count			1		1
	% within ROLEID			100.00%		100.00%
18	Count				3	3
	% within ROLEID				100.00%	100.00%
19	Count				1	1
	% within ROLEID				100.00%	100.00%
20	Count				1	1
	% within ROLEID				100.00%	100.00%
21	Count				1	1
	% within ROLEID				100.00%	100.00%
22	Count		1			1
	% within ROLEID		100.00%			100.00%
Total	Count	1	1	20	125	147
	% within ROLEID	0.70%	0.70%	13.60%	85.00%	100.00%

Questions 2 and 3 had to parts to each of them, if the participant answered the first part with a “yes” then they move to the sub-question which is follows a 5-likert scale; if the participants answer “no” to the first part of the question then that is recorded as a 0. Question 2 aims at asses the understanding and awareness levels for team members in the communication process. Question 3 targeted the level of participation for team members. For question 2, there is a strong skewness in responses towards values 4 and 5 which represent “somewhat agree” and “agree” respectively. Two groups had a significant difference in answers; those were 4th year medical students and student nurses. Approximetly 30% of the participants from those groups responded with “somewhat agree” when asked if they received answers to their questions. Also, 43% of participating dieticians answered “no” to the question of whether they had any questions during rounds.

Table 25 Crosstabulation between Survey question 2 and clinical roles

			Q2			Total
			0	4	5	0
ROLEID	1	Count	4	6	24	34
		% within ROLEID	11.80%	17.60%	70.60%	100.00%
	2	Count	1		3	4
		% within ROLEID	25.00%		75.00%	100.00%
	3	Count	1		3	4
		% within ROLEID	25.00%		75.00%	100.00%
	4	Count	2		11	13
		% within ROLEID	15.40%		84.60%	100.00%
	6	Count	1	2	9	12
		% within ROLEID	8.30%	16.70%	75.00%	100.00%
	7	Count	2	1	29	32
		% within ROLEID	6.30%	3.10%	90.60%	100.00%
	8	Count			9	9
		% within ROLEID			100.00%	100.00%
	10	Count	**1**	**4**	**8**	**13**
		% within ROLEID	**7.70%**	**30.80%**	**61.50%**	**100.00%**
	12	Count			2	2
		% within ROLEID			100.00%	100.00%
	13	Count			1	1

		% within ROLEID			100.00%	100.00%
	14	Count	**1**	**2**	**4**	**7**
		% within ROLEID	**14.30%**	**28.60%**	**57.10%**	**100.00%**
	15	Count	3	1	3	7
		% within ROLEID	42.90%	14.30%	42.90%	100.00%
	16	Count			1	1
		% within ROLEID			100.00%	100.00%
	17	Count			1	1
		% within ROLEID			100.00%	100.00%
	18	Count			3	3
		% within ROLEID			100.00%	100.00%
	19	Count			1	1
		% within ROLEID			100.00%	100.00%
	20	Count			1	1
		% within ROLEID			100.00%	100.00%
	21	Count	1			1
		% within ROLEID	100.00%			100.00%
	22	Count	1			1
		% within ROLEID	100.00%			100.00%
Total		Count	18	16	113	147
		% within ROLEID	12.20%	10.90%	76.90%	100.00%

For question 3, students from medical school and nursing had mixed responses about participating and conveying any important information, 31% and 42% responded by “somewhat agree” to the question, which shows a degree of uncertainty. As for dieticians, 85% replied they had no information to convey during patient rounds activity.

Table 26 Cross tabulation between Survey question 3 and clinical roles

			Q3				Total
			0	3	4	5	0
ROLEID	1	Count	4		3	27	34

		% within ROLEID	11.80%		8.80%	79.40%	100.00%
	2	Count				4	4
		% within ROLEID				100.00%	100.00%
	3	Count				4	4
		% within ROLEID				100.00%	100.00%
	4	Count	1		2	10	13
		% within ROLEID	7.70%		15.40%	76.90%	100.00%
	6	Count	2		1	9	12
		% within ROLEID	16.70%		8.30%	75.00%	100.00%
	7	Count		1	2	29	32
		% within ROLEID		3.10%	6.30%	90.60%	100.00%
	8	Count				9	9
		% within ROLEID				100.00%	100.00%
	10	Count	**1**		**4**	**8**	**13**
		% within ROLEID	**7.70%**		**30.80%**	**61.50%**	**100.00%**
	12	Count				2	2
		% within ROLEID				100.00%	100.00%
	13	Count				1	1
		% within ROLEID				100.00%	100.00%
	14	Count	**1**		**3**	**3**	**7**
		% within ROLEID	**14.30%**		**42.90%**	**42.90%**	**100.00%**
	15	Count	**6**			**1**	**7**
		% within ROLEID	**85.70%**			**14.30%**	**100.00%**
	16	Count	1				1
		% within ROLEID	100.00%				100.00%
	17	Count		1			1
		% within ROLEID		100.00%			100.00%
	18	Count				3	3
		% within ROLEID				100.00%	100.00%
	19	Count	1				1
		% within ROLEID	100.00%				100.00%
	20	Count				1	1

		% within ROLEID				100.00%	100.00%
	21	Count	1				1
		% within ROLEID	100.00%				100.00%
	22	Count	1				1
		% within ROLEID	100.00%				100.00%
Total		Count	19	2	15	111	147
		% within ROLEID	12.90%	1.40%	10.20%	75.50%	100.00%

Finally, question 4 aims at assessing the overall effectiveness of communication during patient rounds activity. The majority of nursing students (57%) evaluated the overall effectiveness of communication as “somewhat effective”. While 7% of 4th year medical students rated the overall communication as “neutrally effective”, 23% rated communication as “somewhat effective”, and 69% responded by “Highly effective”. For all other clinical roles, most of the answers were skewed towards “highly effective”.

Table 27 Crosstabulation between Survey question 4 and clinical roles

			Q4				Total
			1	3	4	5	1
ROLEID	1	Count	1		6	27	34
		% within ROLEID	2.90%		17.60%	79.40%	100.00%
	2	Count				4	4
		% within ROLEID				100.00%	100.00%
	3	Count				4	4
		% within ROLEID				100.00%	100.00%
	4	Count			1	12	13
		% within ROLEID			7.70%	92.30%	100.00%
	6	Count			1	11	12
		% within ROLEID			8.30%	91.70%	100.00%
	7	Count			6	26	32
		% within ROLEID			18.80%	81.30%	100.00%
	8	Count				9	9

		% within ROLEID				100.00%	100.00%
	10	Count		**1**	**3**	**9**	13
		% within ROLEID		**7.70%**	**23.10%**	**69.20%**	100.00%
	12	Count			2		2
		% within ROLEID			100.00%		100.00%
	13	Count				1	1
		% within ROLEID				100.00%	100.00%
	14	Count			**4**	**3**	**7**
		% within ROLEID			**57.10%**	**42.90%**	**100.00%**
	15	Count			1	6	7
		% within ROLEID			14.30%	85.70%	100.00%
	16	Count				1	1
		% within ROLEID				100.00%	100.00%
	17	Count				1	1
		% within ROLEID				100.00%	100.00%
	18	Count				3	3
		% within ROLEID				100.00%	100.00%
	19	Count				1	1
		% within ROLEID				100.00%	100.00%
	20	Count				1	1
		% within ROLEID				100.00%	100.00%
	21	Count				1	1
		% within ROLEID				100.00%	100.00%
	22	Count				1	1
		% within ROLEID				100.00%	100.00%
Total		Count	1	1	24	121	147
		% within ROLEID	0.70%	0.70%	16.30%	82.30%	100.00%

4.3.3 Survey Question Validation

The survey is designed to go from detailed questions to one general question about the overall communication of a given day. As discussed before, the main aim behind conducting post-observation surveys is to use survey results as outcome measurements to observation data. We are interested in finding one single outcome measurement, instead of four outcomes, to be used throughout the analysis phase. In order to do so, a significant correlation is required between questions 1,2, and 3; and question 4. Therefore, we conducted Pearson's correlation test on the data to find the degree of correlation between responses from all survey questions.

Table 28 shows the results of running Pearson correlation on all four survey questions. By looking at the last row in the table, namely q4, one can deduct that there are very strong positive correlation between questions 1,2,3 with question 4. Question 1 has p-value of 0.991 and the value of alpha is close to 0; question 2 has p-value of 0.872 and alpha is close to 0, question 3 has p-value of 0.703 and alpha = 0.001; this shows a strong direct relationship between all variables and variable q4. Therefore, question 4 can be used as a single outcome measurement since it directly represents the rest of the survey questions.

Table 28 Correlation table analyzing the correlation levels between survey questions

		q1	**q2**	**q3**	**q4**
q1	Pearson Correlation	1			
	Sig. (2-tailed)				
q2	Pearson Correlation	**.870****	1		
	Sig. (2-tailed)	**0**			
q3	Pearson Correlation	**.742****	**.854****	1	
	Sig. (2-tailed)	**0**	**0**		
q4	Pearson Correlation	**.991****	**.872****	**.703****	1
	Sig. (2-tailed)	**0**	**0**	**0.001**	
**. Correlation is significant at the 0.01 level (2-tailed).					

4.3.4 Linear Regression

Building off from the previous section, the next step after analyzing observation and survey variables independently is to analyzing both variables against each other. We use linear regression with survey question 4 as the outcome (or y variable in the equation), and observation variables as predictors in the model. The linear model was generated based on all data collected on weekdays; Table 29 shows the results for the Anova test.

Table 29 Anova results for the regresion model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.574	26	.137	.542	.923[a]
	Residual	4.312	17	.254		
	Total	7.886	43			

a. Predictors: (Constant), mouse, mis1, tel_y, relat_y, readinfo, aler_n, mis2, unrlat_y, sid_n, tel_n, teaching, aler_p, pag_y, sid_y, ext_n, pag_n, nonverba, requesti, verbal, giveinfo, relat_n, aler_y, repititi, requestn, infotolp, ext_y

b. Dependent Variable: q4

c. Selecting only cases for which day_typ = week day

Table 30 shows the results for the regression model, it can be noted that many variables do not serve as strong predictors to question 4 with some exceptions. 5 variables showed significant levels of prediction to question 4 and they are: accepted side conversations, accepted external interruptions, rejected external interruptions, and the Attending correcting themselves. When the Attending stops the conversation due to a side conversation by either participating in the side conversation or even by pausing their conversation, this affects the overall effectiveness of communication from the clinical team’s perspective. Also, when external interruptions occur during patient visit this affect team communication, and what is interesting is that any reaction of the Attending to the interruption will yield similar results. This means that the degree of discomfort that an external interruption brings into the conversation is significant even if the Attending does not pause for the interruption. Finally, when the Attending makes a mistake and then corrects that mistake, this causes a degree of discontinuity, which leads to team members having less rating for the overall effectiveness of communication.

Table 30 A detailed breakdown of the Regression model showing, coefficients, t value, and significance for each variable in the model

Coefficients[a,b]						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
			Std. Error	Beta		
1	(Constant)	4.892	0.309		15.811	0
	infotolp	-0.087	0.057	-0.918	-1.533	0.144
	verbal	-0.036	0.059	-0.234	-0.616	0.546
	nonverba	0.001	0.05	0.004	0.011	0.992
	repititi	0.044	0.158	0.117	0.28	0.783
	giveinfo	0.049	0.091	0.19	0.542	0.595
	requesti	0.09	0.067	0.813	1.351	0.194
	requestn	0.033	0.064	0.272	0.521	0.609
	teaching	-0.01	0.042	-0.081	-0.239	0.814
	relat_y	-0.072	0.091	-0.278	-0.783	0.445
	relat_n	-0.26	0.472	-0.22	-0.551	0.589
	unrlat_y	0.595	0.547	0.354	1.088	0.292
	sid_y	**0.704**	**0.374**	**0.704**	**1.885**	**0.077**
	sid_n	-0.043	0.059	-0.233	-0.724	0.479
	ext_y	**-0.809**	**0.34**	**-2.015**	**-2.378**	**0.029**
	ext_n	**1.034**	**0.464**	**0.934**	**2.23**	**0.04**
	aler_y	-0.112	0.254	-0.236	-0.443	0.664
	aler_n	0.035	0.046	0.285	0.763	0.456
	aler_p	-0.007	0.005	-0.392	-1.205	0.245
	pag_y	-0.427	0.366	-0.32	-1.168	0.259
	pag_n	-0.252	0.401	-0.171	-0.628	0.538
	tel_y	-0.164	0.54	-0.098	-0.304	0.765
	tel_n	0.49	0.284	0.501	1.724	0.103
	mis1	**3.573**	**1.652**	**1.258**	**2.163**	**0.045**

mis2	0.125	0.373	0.085	0.336	0.741
readinfo	**0.304**	**0.157**	**0.733**	**1.935**	**0.07**
mouse	0.064	0.106	0.159	0.609	0.551

a. Dependent Variable: q4

b. Selecting only cases for which day_typ = week day

CHAPTER 5 - DISCUSSION

The primary purpose of this study research is to use qualitative approach to investigate communication events, interruptions, and interactions that the clinical team experienced within the context of critical care. The data collected through reported cases and observation resulted in 3 proximate outcomes that assist further understanding of the problem: 1) frequency of occurrence of instances, 2) representation of clinician-clinician interaction, 3) representation of clinician-computer interaction.

5.1 Communication instances frequency

We identified 6 main communication factors that repeatedly occurred during team communication with the Attending Physician: 1) patient information conveyed to the Attending, 2) feedback provided to the Attending, 3) frequency of communication done by the Attending, 4) interruptions by the team, 5) interruptions by technological devices, 6) Attending's interaction with computers. Table 13 Frequency of clinical communication events shows that the majority of communication done in the ICU is done for the purpose of either giving or receiving information, which agrees with the findings of Coiera and Moss with regards to the operating room and emergency departments [82, 99]. Communication done by the Attending to the team members was more than double the communication done by the team members to the Attending, which shows that more information is being transferred from the Attending which is logical due to the role and responsibilities of the Attending towards the patients and the team. Moreover, the Attending provided feedback, verbal and nonverbal, 1.5 more times than the communication instances they received from the team. This shows the persistency of the Attending to acknowledge and confirm the messages they received and also, an indication to the team to follow the same habit of clearly showing their understanding of a given statement.

A significant number of interruptions were observed during communication. The frequency of an interruption caused by clinician was approximately triple the frequency of an interruption caused by technology-aided devices. This ratio agrees with the findings of Patel at al., which suggests that human interruptions are usually twice as frequent to technological interruptions [100]. From observation, we identify that human interruptions, even though more frequent, can be controlled by increase in awareness and training, the reason for this belief is that all interruption variables, such as the interrupter, are present in the room. However, interruptions caused by technologies, such as telephones and pagers, might be harder to control since the interrupter is not on-site; nevertheless, options such as putting personal cellphones on silent could minimize this frequency.

5.2 Statistical discussion

As discussed in the results section, there are strong correlations between observation and survey variables. Most of the analysis done in the results section examined the data at the patient visit level, with n=279. However, it is as important to look at the data at the session level, in other words, to aggregate the data into studies. Since we conducted 18 studies, where a study is equal to a day in the ICU, then we aggregated all patient data for a given day into a total number for each variable. Moreover, observation data was aggregated from sub-categories into categories, for example, instead of two variables for verbal and non-verbal feedback, one category was created combining both variables. Initially this step was of importance because if relationships can be found at higher levels, between categories, then further and finer analysis can be done to find which sub-category had the strongest correlation level. So, we followed a top-down approach where we analyzed high level categories then based on correlation results we focused on finer levels.

Table 31 shows the aforementioned approach, major communication categories were developed by aggregating each variable within a category. Observation data has 8 main communication categories, they are: information to the Attending physician, feedback, repetitions, tasks done by Attending physician, human interruptions, technology-aided devices interruptions, mistakes, and computer interactions. Results suggest that there are strong relationships between conveying information to the Attending physician and the feedback provided by the Attending, which is a positive sign of effective communication because it shows two way communications. Also, as more information is being conveyed to the Attending, more communication is done by the Attending. The more the Attending uses the computer system in the room, the higher the level of interruptions caused by clinicians. Moreover, an increase in the level of interruptions caused by technology-aided devices causes an increase in the level of interruptions by clinicians.

Mistakes that occurred during observation had several important relationships with other variables. The chance of a communication error occurring is positively correlated with information being conveyed to the Attending and the Attending requesting information or new tasks to be done. Also, as more mistakes occur during communication, the more feedback the Attending provides to the team. Finally, there is a strong positive correlation between the occurrence of interruptions caused by technology-aided devices and the occurrence of communication mistakes.

Table 31 Pearson's correlation for observation variables per day

		InfoToLP	Feedback	Repititions	Tasks	HumanInterruptions	TechInterruptions	Mistakes	ComputerInteractions
InfoToLP	Pearson Correlation	1							
	Sig. (2-tailed)								
Feedback	Pearson Correlation	**.598****	1						
	Sig. (2-tailed)	**0.009**							
Repititions	Pearson Correlation	-0.111	0.001	1					
	Sig. (2-tailed)	0.662	0.998						
Tasks	Pearson Correlation	**.521***	**.686****	0.345	1				
	Sig. (2-tailed)	**0.027**	**0.002**	0.161					
HumanInterruptions	Pearson Correlation	0.212	0.328	-0.041	-0.039	1			
	Sig. (2-tailed)	0.399	0.184	0.872	0.877				
TechInterruptions	Pearson Correlation	**.572***	**.787****	-0.057	**.614****	**.540***	1		
	Sig. (2-tailed)	**0.013**	**0**	0.823	**0.007**	**0.021**			
Mistakes	Pearson Correlation	**.487***	**.610****	-0.035	**.478***	0.287	**.670****	1	

	Sig. (2-tailed)	**0.041**	**0.007**	0.889	**0.045**	0.248	**0.002**		
ComputerInteractions	Pearson Correlation	-0.246	-0.16	0.007	-0.03	**-.574***	-0.41	-0.148	1
	Sig. (2-tailed)	0.325	0.525	0.977	0.905	**0.013**	0.091	0.558	

5.3 Clinicians Interaction

When clinicians communicate numerous factors are taken into consideration which makes the communication process complicated. We identified that communication among clinicians is affected tacit knowledge and external activity. The way a clinician was trained, the level of education, and the years of experience shape how they formulate or perceive a message. During the study we observed that clinicians with more of the previously mentioned factors can more accurately articulate their messages. Similarly, there is a language factor which represents two aspects: The first is good use of English for non-native speakers, and secondly, the use of standardized clinical terminology during communication. This agrees with the findings of a study surveying 64 members of the National Association of School Nurses, which suggested that the use of standardized terminology among nurses reduces symptoms after intervention, and enhances patient safety [101].

External factors seem to limit the communication process rather than facilitate. The frequent occurrence of side conversations, pager and computer alerts, and multitasking presents a disruption to the ongoing conversation and the result was a request to repeat, or a question aimed at continuing the conversation. We also observed team members multitasking during communication, while the justification is understood, the consequence of multitasking can range from mishearing to executing the wrong order and hence, there is a higher chance for medical errors.

5.4 Clinicians and computers

While shadowing the clinical team, several rare instances of human-computer interactions occurred. When reviewing the latest X-Ray for an ICU patient, the image was hard to read and interpret and the Attending reported that the quality of imaging was of fair quality and better representation and quality is needed. Another instance, during patient rounds the Attending requested the medical record of the patient to be retrieved from the system, upon retrieval, the resident notified the Attending of the patient information; however, the Attending realized that the information is incorrect. The resident incorrectly typed the wrong information and the system retrieved the incorrect medical record.

When representing the communication process between clinicians and computers, there are two dimensions to highlight: 1) the user, 2) the computer system. Users must have comprehensive understanding of the system, including usability, and correctly storing and retrieving information, and problem solving skills. As for computer systems, the most important feature is to design a clinician-centered system that will provide convenient design and functionality that suits the needs of clinicians.

5.5 Significant Findings

5.5.1 Specific Aims

After running and analyzing statistical tests on the data, the findings of this work needs to be summarized by looking at the specific aims. The first aim aimed at testing the hypothesis that there is no association between Human-Human and Human-Computer interactions, and the awareness of the daily goals for the clinical team. The p-value was

0.631 which is greater than 0.05, and the correlation level was very weak. The p-value suggests that we retain this hypothesis, which means there is no association between H-H and H-C and the level of awareness of daily goals.

- #1: H-H & H-C ⟺ Awareness of daily goals
  - Pearson correlation = 0.040
  - Alpha= 0.631
  - Retain the null hypothesis

The second specific aim hypothesized that there is no relationship between the use of feedback provided by the Attending, and the level of team satisfaction about the communication. There was a negative correlation value which indicates indirect relationship; however, the correlation level was very small, indicating weak correlation. The p-value was 0.873 which indicates retaining the null hypothesis.

- #2: Feedback ⟺ Satisfaction levels
  - Pearson correlation = -0.013
  - Alpha= 0.873
  - Retain the null hypothesis

The third specific aim hypothesized that there is no relationship between the communication tasks done by the Attending and the level of team participation. Positive correlation was deduced however, the correlation levels were rated as weak; the p-value was 0.05 indicating that we reject the null hypothesis. This means that there is a relationship between Attending's communication and the level of participation for the clinical team.

- #3: Communication tasks ⟺ Participation levels

- Pearson correlation = 0.158
- Alpha= 0.05
- Reject the null hypothesis

Finally, the forth specific aim hypothesized that there is no difference between communication intensity on week days and weekend days. Table 32 two variables had a p-value greater than 0.05, which meant that the null hypothesis for these variables were retained, meaning there are no difference among weekends and weekdays for mistakes made, and Human- Computer interaction. On the contrary, the other three variables had a p-value smaller than 0.05, which meant that we rejected the null hypothesis. This means for feedback, communication tasks, and interruptions there was significant difference between week days and weekends.

- #4: Weekdays ⟺ Weekends
    - Reject the null hypothesis for: feedback, communication tasks, interruptions
    - Retain the null hypothesis for: mistakes, H-C interaction

Table 32 Table showing the difference in communicatio among week days and weekend days

Mean Rank	Feedback	Attending Comm. Tasks	Interruptions	Mistakes	Human-Computer Interaction
Weekday	149	152	154	140	146
Weeken	129	120	116	139	130

d					
Asymp. Sig.	0.014	.001	0.000	0.791	0.105

5.5.2 Other important findings

To summarize our findings for this research work, we summarize selective findings from our statistical analysis. During the observation study, many interruptions were observed from clinicians and from technology aided-devices. The ratio of occurrence of interruptions caused by clinicians to interruptions caused by technology was 3:1, showing that clinicians provide most of the interruptive events during a conversation. Also, the Attending physician provided most of the communication done inside a patient room; most of the Attending's communication was directed towards requesting patient information. Between weekdays and weekends, three variables showed significant difference, with more frequency on weekdays than weekends, those variables are: feedback by the Attending, teaching done by the Attending, and computer interactions by the Attending. Similarly, between large and small team sizes, three variables showed higher frequency to large size teams, those variables are information conveyed to the Attending, mistakes made by the team, feedback provided by the Attending.

Moreover, there was a strong correlation between the occurrence of technology interruptions and information conveyed to the Attending physician, with the frequency of mistakes. Higher frequency of technology interruptions and information sent to the Attending, the higher the frequency of mistakes made, showing a direct relationship.

Also, the higher the frequency of human and technology interruptions, the lower the frequency of computer interactions done by the Attending, showing an indirect relationship. Finally, some of the strong predictors of effective communication were the occurrence of side conversations, external interruptions, mistakes by the attending, and reading electronic patient information, showing a strong impact on the communication outcome.

5.6 Future Direction and limitations

This research focuses on further understanding communication among the clinical team, and rather than clinician-patient communication. Approved by the Institutional Board Review (IRB), our research plan protects all human subjects by abstaining from collecting any patient related information, either unique or non-unique identifiers. Moreover, all survey participants are anonymous, no unique identifying information is collected. The only information collected through the survey instrument is the clinical role of the participant. We believe there could be interesting associations between various clinical roles and their survey answers.

One of the limitations of this study is the limited number of Attending physicians at the ICU. Even though this research is conducted at a 300-bed hospital and 68 ICU bed [102], there is a challenge to find more Attending physicians to shadow during ICU bed rounds. Besides the limited number of Attending physicians, in order to further expand this research, more human power is needed to conduct such a large scale study. One strength of this study is that the ICU clinical team conducted bed rounds in multiple ICUs such as, Burn ICU, Cardiac ICU, Surgical ICU, and Pulmonary ICU. Capturing communication instances from different ICU settings, which operate differently, could enhance data validity across ICU specialties.

Literature review and preliminary results show consistently that there are multiple dimensions to clinical team communication that need to be further studied and carefully analyzed. This research aims at identifying key factors that positively or negatively affect the clinical team communication process. Each communication factor can affect the communication process by facilitating or complicating the exchange of information. The observational study is a start towards an inclusive communication framework that can exhaustively express clinical communication. In order to further understand communication, we will continue to collect and analyze clinical communication cases from literature. We aim to collect more diversified cases; this will provide this research with a strong, solid knowledge base to support our findings.

In the near future, we plan to conduct focus groups among clinical team member groups to elicit team communication details directly from them. In this way, we will supplement our observational and survey work with direct and open-ended details about team communication that might not be readily uncovered by observational or survey work alone. Furthermore, we will shadow additional clinical teams; by studying more clinical specialties in other settings such as the Emergency Room (ER) or Operating Room (OR), we will increase the potential for identifying team communication patterns. We will also conduct more observational studies that will be focused primarily from the point of view and on processes of clinical team members other than attending physicians, such as respiratory therapists, nurses, etc. This will help refine current results and might uncover additional factors. In these next steps, we will digitize our data collection instrument so that it can be used on PDAs and portable devices to facilitate data acquisition.

The ultimate goal of this research is to go beyond the theoretical level into more practical applications. For that reason, we aim to utilize the clinical communication taxonomy, proposed by Gong et al [94], as well as the communication model [15]to build a clinical communication ontology, which to our knowledge, has yet to be built. This core informatics work, once validated, will serve as a fundamental foundation for future communication research in health care and other industries as well by highlighting overlapping behaviors and patterns. Based on its knowledge expression capabilities, such ontology will play an important role in the machine data processing.

In order to design a clinical communication ontology that can serve as an educational instrument, or as part of a medical error reporting system, we plan to organize the ontology into two main divisions: H-H and H-C interactions. Under each division, there will be subdivisions that will follow the clinical communication model. Those subdivisions will aim to organize communication factors under common categories while maintaining independencies and exhaustiveness among factors.

5.7 Conclusion

The significance of clinical communication on health care services and patient outcomes is of utmost significance. Literature discusses the importance of better clinical communication, and previous efforts have been made to study the communication behaviors and patterns among the clinical team. Nevertheless, there is still a need for improvements. We propose a methodology that ensures building on from the findings of previous work and proposes an innovative approach. Our research roadmap highlights the two core steps to link between the current state and the targeted state, namely, data analysis and building a knowledge base through statistical analysis. Finally, the ultimate goal of this research is to develop clinical communication ontology and a web-based educational instrument.

Our research stream aims at contributing to the clinical communication problem at three levels. First, by applying information theory, we proposed the first clinical communication model that represents the communication framework within healthcare with a focus on Human-Human interactions and Human-Computer interactions [15, 94]. Second, at the practical level, we aim at building a clinical communication ontology that is based upon data gleaned from the observational study and data from literature. This ontology will represent possible clinical miscommunication causes, and help health care professionals understand medical incidents and increase their awareness of effective communication. Third, we aim at using the knowledge base from the cases and the ontology to develop an educational instrument that will be implemented within the ICU; its role is to enhance communication within the clinical team by promoting safer and more effective communication.

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APPENDIX

IRB Approval

Institutional Review Board
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August 10, 2010

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Columbia, MO 65211-7100

Dear Dr. Khairat,

Regarding your application for approval of the research project, Knowledge Representation of ICU Communication, the Health Sciences Institutional Review Board (HS IRB) took the following action:

a. The principal investigator on this study is responsible for all aspects and conduct of this study.
b. Approved your study through expedited review [as codified under 45 CFR 46.110 (f) (6, & 7)] on August 10, 2010.
c. Found this protocol, dated June 20, 2010 to impose minimal risk to the research participant.
d. The HS IRB has waived the requirement for the approved consenting personnel to obtain a signed consent form for all research participants in accordance with 45 CFR 46.116 (d). Although the requirement to obtain a signature has been waived, a copy of the consent script that was approved on August 10, 2010 must be given to each research participant to keep for his or her records.
e. Reviewed and approved any questionnaires or surveys that were submitted with your application.
f. Found that there is no HIPAA requirement for this project.
g. The HS IRB has determined that the degree of risk is such that the approval for this protocol will expire on August 10, 2011. A Continuing Review Report must be submitted a minimum of one month prior to this date.
h. Upon completion of the study a Completion Form must be submitted to the HS IRB office. If the closure is not documented on the Completion Form, you may close the study at the time of the annual review.

Please reference IRB Project # 1170957 in all future communications regarding this project.

Pursuant to the HS IRB conflict of interest policy, investigators who are HS IRB members do not vote on protocols in which they are involved.

Death occurring in a study at this site must be reported to the HS IRB office within 24 hours of occurrence, whether or not the death is related to the study. All on-site serious adverse events meeting criteria must be reported to the HS IRB office within five (5) days of occurrence.

No change may be made in an approved protocol or recruitment materials unless the change is submitted to and approved by the HS IRB.
Do not depend on the HS IRB for your record keeping.

Sincerely,

Niels Beck, PhD
Chair

Enclosure

Figure 17 Letter of IRB approval

Detailed Descriptive Analysis

Table 33 Descriptive analysis for each variable in the observation checklist

			Statistic	Std. Error
infotolp	Mean		6.60	.408
	95% Confidence Interval for Mean	Lower Bound	5.79	
		Upper Bound	7.41	
	5% Trimmed Mean		6.29	
	Median		6.00	
	Variance		15.641	
	Std. Deviation		3.955	
	Minimum		1	
	Maximum		20	
	Range		19	
	Interquartile Range		4	
	Skewness		1.120	.249
	Kurtosis		1.141	.493
verbal	Mean		4.01	.258
	95% Confidence Interval for Mean	Lower Bound	3.50	
		Upper Bound	4.52	
	5% Trimmed Mean		3.88	

	Median	4.00	
	Variance	6.247	
	Std. Deviation	2.499	
	Minimum	0	
	Maximum	13	
	Range	13	
	Interquartile Range	4	
	Skewness	.921	.249
	Kurtosis	1.128	.493
nonverba	Mean	4.40	.317
	95% Confidence Interval for Mean Lower Bound	3.78	
	Upper Bound	5.03	
	5% Trimmed Mean	4.26	
	Median	4.00	
	Variance	9.426	
	Std. Deviation	3.070	
	Minimum	0	
	Maximum	15	
	Range	15	
	Interquartile Range	4	

	Skewness	.893	.249
	Kurtosis	.605	.493
repititi	Mean	.98	.117
	95% Confidence Interval for Mean Lower Bound	.75	
	Upper Bound	1.21	
	5% Trimmed Mean	.87	
	Median	1.00	
	Variance	1.290	
	Std. Deviation	1.136	
	Minimum	0	
	Maximum	4	
	Range	4	
	Interquartile Range	1	
	Skewness	1.122	.249
	Kurtosis	.461	.493
giveinfo	Mean	1.44	.152
	95% Confidence Interval for Mean Lower Bound	1.13	
	Upper Bound	1.74	
	5% Trimmed Mean	1.30	
	Median	1.00	

	Variance	2.184	
	Std. Deviation	1.478	
	Minimum	0	
	Maximum	8	
	Range	8	
	Interquartile Range	2	
	Skewness	1.434	.249
	Kurtosis	3.206	.493
requesti	Mean	6.27	.403
	95% Confidence Interval for Mean Lower Bound	5.46	
	Upper Bound	7.07	
	5% Trimmed Mean	6.03	
	Median	6.00	
	Variance	15.294	
	Std. Deviation	3.911	
	Minimum	0	
	Maximum	19	
	Range	19	
	Interquartile Range	4	
	Skewness	.880	.249

	Kurtosis	.818	.493
requestn	Mean	3.69	.297
	95% Confidence Interval for Mean Lower Bound	3.10	
	Upper Bound	4.28	
	5% Trimmed Mean	3.44	
	Median	3.00	
	Variance	8.302	
	Std. Deviation	2.881	
	Minimum	0	
	Maximum	20	
	Range	20	
	Interquartile Range	3	
	Skewness	2.276	.249
	Kurtosis	10.131	.493
teaching	Mean	3.41	.301
	95% Confidence Interval for Mean Lower Bound	2.82	
	Upper Bound	4.01	
	5% Trimmed Mean	3.18	
	Median	3.00	
	Variance	8.503	

	Std. Deviation	2.916	
	Minimum	0	
	Maximum	14	
	Range	14	
	Interquartile Range	4	
	Skewness	1.192	.249
	Kurtosis	1.610	.493
relat_y	Mean	1.14	.137
	95% Confidence Interval for Mean Lower Bound	.87	
	Upper Bound	1.41	
	5% Trimmed Mean	.98	
	Median	1.00	
	Variance	1.776	
	Std. Deviation	1.333	
	Minimum	0	
	Maximum	7	
	Range	7	
	Interquartile Range	2	
	Skewness	1.801	.249
	Kurtosis	4.160	.493

relat_n	Mean	.07	.031
	95% Confidence Interval for Mean Lower Bound	.01	
	Upper Bound	.14	
	5% Trimmed Mean	.02	
	Median	.00	
	Variance	.091	
	Std. Deviation	.302	
	Minimum	0	
	Maximum	2	
	Range	2	
	Interquartile Range	0	
	Skewness	4.417	.249
	Kurtosis	20.936	.493
unrlat_y	Mean	.05	.023
	95% Confidence Interval for Mean Lower Bound	.01	
	Upper Bound	.10	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.051	
	Std. Deviation	.226	

	Minimum	0	
	Maximum	1	
	Range	1	
	Interquartile Range	0	
	Skewness	4.047	.249
	Kurtosis	14.689	.493
sid_y	Mean	.12	.037
	95% Confidence Interval for Mean Lower Bound	.04	
	Upper Bound	.19	
	5% Trimmed Mean	.06	
	Median	.00	
	Variance	.126	
	Std. Deviation	.355	
	Minimum	0	
	Maximum	2	
	Range	2	
	Interquartile Range	0	
	Skewness	3.131	.249
	Kurtosis	9.958	.493
sid_n	Mean	2.02	.213

	95% Confidence Interval for Mean Lower Bound	1.60	
	Upper Bound	2.44	
	5% Trimmed Mean	1.82	
	Median	2.00	
	Variance	4.258	
	Std. Deviation	2.063	
	Minimum	0	
	Maximum	11	
	Range	11	
	Interquartile Range	3	
	Skewness	1.569	.249
	Kurtosis	3.377	.493
ext_y	Mean	.29	.084
	95% Confidence Interval for Mean Lower Bound	.12	
	Upper Bound	.45	
	5% Trimmed Mean	.16	
	Median	.00	
	Variance	.659	
	Std. Deviation	.812	
	Minimum	0	

	Maximum	6	
	Range	6	
	Interquartile Range	0	
	Skewness	4.482	.249
	Kurtosis	26.510	.493
ext_n	Mean	.05	.028
	95% Confidence Interval for Mean Lower Bound	.00	
	Upper Bound	.11	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.072	
	Std. Deviation	.269	
	Minimum	0	
	Maximum	2	
	Range	2	
	Interquartile Range	0	
	Skewness	5.589	.249
	Kurtosis	33.599	.493
aler_y	Mean	.43	.078
	95% Confidence Interval for Mean Lower Bound	.27	

	Upper Bound	.58	
	5% Trimmed Mean	.31	
	Median	.00	
	Variance	.570	
	Std. Deviation	.755	
	Minimum	0	
	Maximum	4	
	Range	4	
	Interquartile Range	1	
	Skewness	2.328	.249
	Kurtosis	6.594	.493
aler_n	Mean	1.83	.263
	95% Confidence Interval for Mean Lower Bound	1.31	
	Upper Bound	2.35	
	5% Trimmed Mean	1.46	
	Median	1.00	
	Variance	6.508	
	Std. Deviation	2.551	
	Minimum	0	
	Maximum	20	

	Range	20	
	Interquartile Range	1	
	Skewness	5.006	.249
	Kurtosis	30.976	.493
aler	Mean	2.26	.288
	95% Confidence Interval for Mean Lower Bound	1.68	
	Upper Bound	2.83	
	5% Trimmed Mean	1.80	
	Median	1.00	
	Variance	7.784	
	Std. Deviation	2.790	
	Minimum	1	
	Maximum	20	
	Range	19	
	Interquartile Range	1	
	Skewness	4.588	.249
	Kurtosis	24.933	.493
aler_p	Mean	19.89	3.503
	95% Confidence Interval for Mean Lower Bound	12.93	
	Upper Bound	26.85	

	5% Trimmed Mean	16.55	
	Median	.00	
	Variance	1.153E3	
	Std. Deviation	33.962	
	Minimum	0	
	Maximum	100	
	Range	100	
	Interquartile Range	33	
	Skewness	1.547	.249
	Kurtosis	1.001	.493
pag_y	Mean	.15	.043
	95% Confidence Interval for Mean Lower Bound	.06	
	Upper Bound	.23	
	5% Trimmed Mean	.09	
	Median	.00	
	Variance	.171	
	Std. Deviation	.414	
	Minimum	0	
	Maximum	2	
	Range	2	

	Interquartile Range	0	
	Skewness	2.883	.249
	Kurtosis	8.168	.493
pag_n	Mean	.14	.036
	95% Confidence Interval for Mean Lower Bound	.07	
	Upper Bound	.21	
	5% Trimmed Mean	.10	
	Median	.00	
	Variance	.120	
	Std. Deviation	.347	
	Minimum	0	
	Maximum	1	
	Range	1	
	Interquartile Range	0	
	Skewness	2.130	.249
	Kurtosis	2.590	.493
tel_y	Mean	.10	.031
	95% Confidence Interval for Mean Lower Bound	.04	
	Upper Bound	.16	
	5% Trimmed Mean	.05	

	Median	.00	
	Variance	.088	
	Std. Deviation	.296	
	Minimum	0	
	Maximum	1	
	Range	1	
	Interquartile Range	0	
	Skewness	2.793	.249
	Kurtosis	5.924	.493
tel_n	Mean	.22	.043
	95% Confidence Interval for Mean Lower Bound	.14	
	Upper Bound	.31	
	5% Trimmed Mean	.19	
	Median	.00	
	Variance	.175	
	Std. Deviation	.419	
	Minimum	0	
	Maximum	1	
	Range	1	
	Interquartile Range	0	

	Skewness	1.350	.249
	Kurtosis	-.183	.493
mis1	Mean	.01	.011
	95% Confidence Interval for Mean Lower Bound	-.01	
	Upper Bound	.03	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.011	
	Std. Deviation	.103	
	Minimum	0	
	Maximum	1	
	Range	1	
	Interquartile Range	0	
	Skewness	9.695	.249
	Kurtosis	94.000	.493
mis2	Mean	.09	.033
	95% Confidence Interval for Mean Lower Bound	.02	
	Upper Bound	.15	
	5% Trimmed Mean	.03	
	Median	.00	

	Variance	.100	
	Std. Deviation	.317	
	Minimum	0	
	Maximum	2	
	Range	2	
	Interquartile Range	0	
	Skewness	4.005	.249
	Kurtosis	17.065	.493
readinfo	Mean	.93	.125
	95% Confidence Interval for Mean Lower Bound	.68	
	Upper Bound	1.17	
	5% Trimmed Mean	.78	
	Median	1.00	
	Variance	1.468	
	Std. Deviation	1.211	
	Minimum	0	
	Maximum	6	
	Range	6	
	Interquartile Range	1	
	Skewness	1.740	.249

	Kurtosis	3.613	.493
readxray	Mean	.06	.030
	95% Confidence Interval for Mean Lower Bound	.01	
	Upper Bound	.12	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.082	
	Std. Deviation	.286	
	Minimum	0	
	Maximum	2	
	Range	2	
	Interquartile Range	0	
	Skewness	4.929	.249
	Kurtosis	26.184	.493
keyboard	Mean	.04	.034
	95% Confidence Interval for Mean Lower Bound	-.02	
	Upper Bound	.11	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.106	

	Std. Deviation	.325	
	Minimum	0	
	Maximum	3	
	Range	3	
	Interquartile Range	0	
	Skewness	8.549	.249
	Kurtosis	76.303	.493
mouse	Mean	.14	.081
	95% Confidence Interval for Mean Lower Bound	-.02	
	Upper Bound	.30	
	5% Trimmed Mean	.00	
	Median	.00	
	Variance	.615	
	Std. Deviation	.784	
	Minimum	0	
	Maximum	7	
	Range	7	
	Interquartile Range	0	
	Skewness	7.676	.249
	Kurtosis	64.870	.493

Frequency Tables

Table 34 Frequency table for variable date

date				
date	Frequency	Percent	Cumulative Frequency	Cumulative Percent
31JAN2011	10	66.67	10	66.67
08FEB2011	1	6.67	11	73.33
11FEB2011	4	26.67	15	100.00

Table 35 Frequency table for day of the week

dayofwee				
dayofwee	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
1	10	66.67	10	66.67
2	1	6.67	11	73.33
5	4	26.67	15	100.00

Table 36 Frequency table for number of patients

numofpat				
numofpat	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
13	5	33.33	5	33.33
18	10	66.67	15	100.00

Table 37 Frequency table for team size

teamsize				
teamsize	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
6	3	20.00	3	20.00
7	4	26.67	7	46.67
8	6	40.00	13	86.67
9	2	13.33	15	100.00

Table 38 Frequency table for variable team size

team_c				
team_c	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
1	13	86.67	13	86.67
2	2	13.33	15	100.00

Table 39 Frequency table for patient visit

patienti				
patienti	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
1	1	6.67	1	6.67
5	1	6.67	2	13.33
7	1	6.67	3	20.00
10	1	6.67	4	26.67
11	2	13.33	6	40.00
12	2	13.33	8	53.33
13	2	13.33	10	66.67
14	1	6.67	11	73.33
15	1	6.67	12	80.00
16	1	6.67	13	86.67
17	1	6.67	14	93.33
18	1	6.67	15	100.00

Table 40 Frequency table for variable information to LP

infotolp				
infotolp	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
2	3	20.00	3	20.00
3	2	13.33	5	33.33
4	2	13.33	7	46.67
5	2	13.33	9	60.00
6	2	13.33	11	73.33
7	1	6.67	12	80.00
9	2	13.33	14	93.33
20	1	6.67	15	100.00

Table 41 Frequency table for variable verbal feedback

verbal				
verbal	Frequency	Percent	Cumulative Frequency	Cumulative Percent
1	2	13.33	2	13.33
2	2	13.33	4	26.67
3	5	33.33	9	60.00
4	3	20.00	12	80.00
5	1	6.67	13	86.67
7	1	6.67	14	93.33
8	1	6.67	15	100.00

Table 42 Frequency table for variable non-verbal feedback

nonverba				
nonverba	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	1	6.67	1	6.67
2	3	20.00	4	26.67
3	2	13.33	6	40.00
4	3	20.00	9	60.00
5	1	6.67	10	66.67
6	2	13.33	12	80.00
7	2	13.33	14	93.33
11	1	6.67	15	100.00

Table 43 Frequency table for variable repetitions

repitititi				
repititi	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	10	66.67	10	66.67
1	3	20.00	13	86.67
2	2	13.33	15	100.00

Table 44 Frequency table for variable give informaiton

giveinfo				
giveinfo	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	7	46.67	7	46.67
1	5	33.33	12	80.00
3	1	6.67	13	86.67
4	1	6.67	14	93.33
6	1	6.67	15	100.00

Table 45 Frequency table for variable request information

requesti				
requesti	Frequency	Percent	Cumulative Frequency	Cumulative Percent
2	1	6.67	1	6.67
3	3	20.00	4	26.67
4	2	13.33	6	40.00
5	3	20.00	9	60.00
6	1	6.67	10	66.67
7	2	13.33	12	80.00
8	1	6.67	13	86.67
11	1	6.67	14	93.33
18	1	6.67	15	100.00

Table 46 Frequency table for variable request new task

requestn				
requestn	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
1	1	6.67	1	6.67
2	3	20.00	4	26.67
3	4	26.67	8	53.33
4	3	20.00	11	73.33
6	2	13.33	13	86.67
7	1	6.67	14	93.33
8	1	6.67	15	100.00

Table 47 Frequency table for variable teaching

teaching				
teaching	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
2	3	20.00	3	20.00
3	1	6.67	4	26.67
4	2	13.33	6	40.00
5	2	13.33	8	53.33
6	1	6.67	9	60.00
7	2	13.33	11	73.33
8	3	20.00	14	93.33
10	1	6.67	15	100.00

Table 48 Frequency table for variable related question with reponse yes

relat_y				
relat_y	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	4	26.67	4	26.67
1	5	33.33	9	60.00
2	4	26.67	13	86.67
3	1	6.67	14	93.33
4	1	6.67	15	100.00

Table 49 Frequency table for variable related question with response no

relat_n				
relat_n	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	15	100.00	15	100.00

Table 50 Frequency table for variable unrelatred questions with response yes

unrlat_y				
unrlat_y	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	13	86.67	13	86.67
1	2	13.33	15	100.00

Table 51 Frequency table for variable unrelated question with response no

unrlat_n				
unrlat_n	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	15	100.00	15	100.00

Table 52Frequency table for variable side oncversation with response yes

sid_y				
si d_y	**Frequency**	**Perce nt**	**Cumulative Frequency**	**Cumulativ e Percent**
0	13	86.67	13	86.67
1	2	13.33	15	100.00

Table 53 Frequency table for variable side oncversation with reponse no

sid_n				
sid_n	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	5	33.33	5	33.33
1	5	33.33	10	66.67
2	3	20.00	13	86.67
4	1	6.67	14	93.33
7	1	6.67	15	100.00

Table 54 Frequency table for variable external interruption with response yes

ext_y				
ext_y	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	13	86.67	13	86.67
1	1	6.67	14	93.33
2	1	6.67	15	100.00

Table 55 Frequency table for variable external interruption with response no

ext_n				
ext_n	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	13	86.67	13	86.67
1	2	13.33	15	100.00

Table 56 Frequency table for variable alert with response yes

aler_y				
aler_y	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	13	86.67	13	86.67
1	1	6.67	14	93.33
3	1	6.67	15	100.00

Table 57 Frequency table for variable alert with response no

aler_n				
aler_n	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	10	66.67	10	66.67
1	1	6.67	11	73.33
2	1	6.67	12	80.00
3	1	6.67	13	86.67
4	1	6.67	14	93.33
20	1	6.67	15	100.00

Table 58 Frequency table for variable pager with response yes

pag_y				
pag_y	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	15	100.00	15	100.00

Table 59 Frequency table for variable pager with response no

pag_n				
pag_n	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	15	100.00	15	100.00

Table 60 Frequency table for variable telephone with response yes

tel_y				
tel_y	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	13	86.67	13	86.67
1	1	6.67	14	93.33
2	1	6.67	15	100.00

Table 61 Frequency table for variable telephone with response no

tel_n				
te l_n	Frequency	Perce nt	Cumulative Frequency	Cumulative Percent
0	14	93.33	14	93.33
1	1	6.67	15	100.00

Table 62 Frequency table for variable LP corrects themselves

mis1				
mis1	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	15	100.00	15	100.00

Table 63 Frequency table for variable LP corrects team

mis2				
mis2	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	12	80.00	12	80.00
1	3	20.00	15	100.00

Table 64 Frequency table for variable read information

readinfo				
readinfo	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	12	80.00	12	80.00
1	1	6.67	13	86.67
2	1	6.67	14	93.33
4	1	6.67	15	100.00

Table 65 Frequency table for variable read imaging

readxray				
readxray	**Frequency**	**Percent**	**Cumulative Frequency**	**Cumulative Percent**
0	15	100.00	15	100.00

Table 66 Frequency table for variable keyboard

keyboard				
keyboard	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	15	100.00	15	100.00

Table 67 Frequency table for variable mouse

mouse				
mouse	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	14	93.33	14	93.33
1	1	6.67	15	100.00

Frequency Histograms

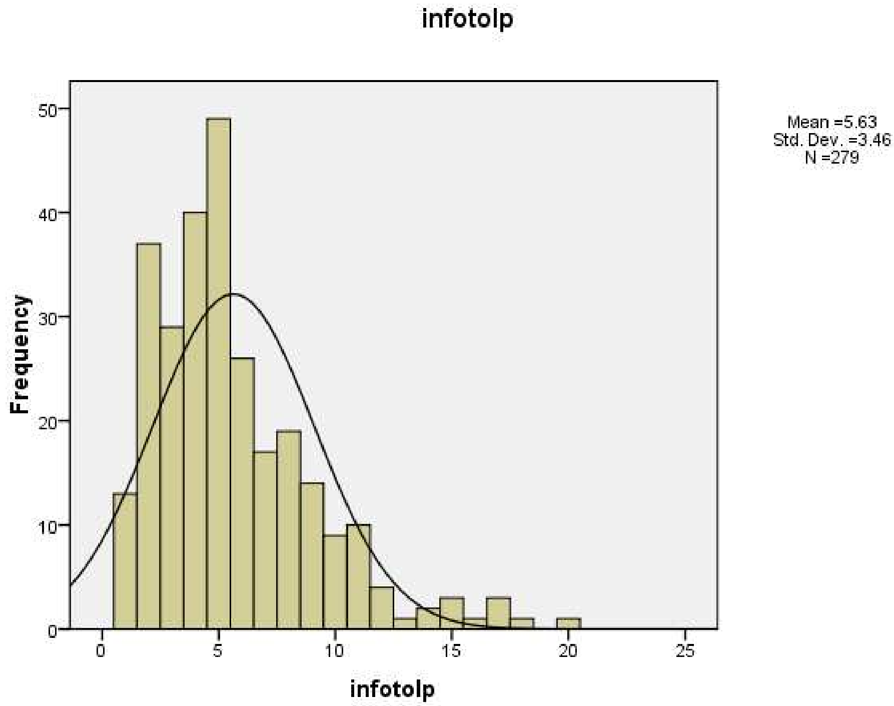

Figure 18 Frequency histogram for variable informaiton to LP

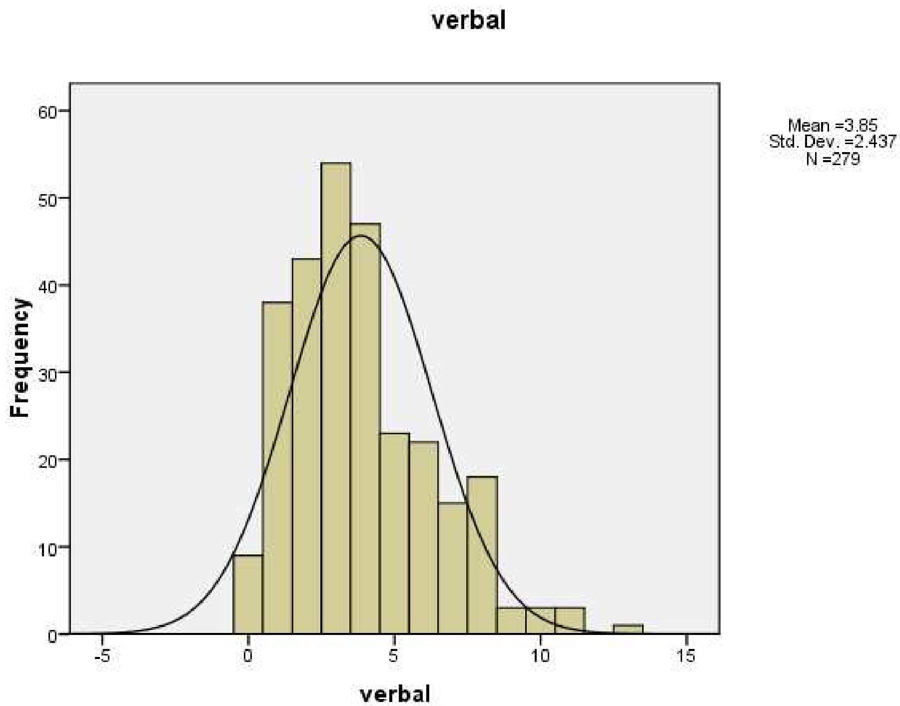

Figure 19 Frequency histogram for variable verbal feedback

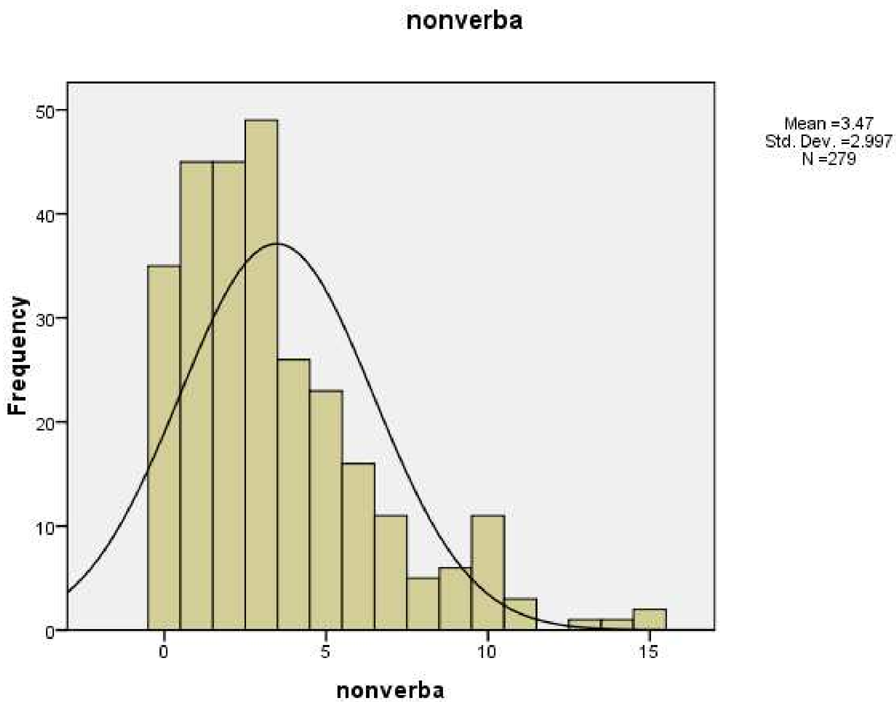

Figure 20 Frequency histogram for variable non-verbal feedback

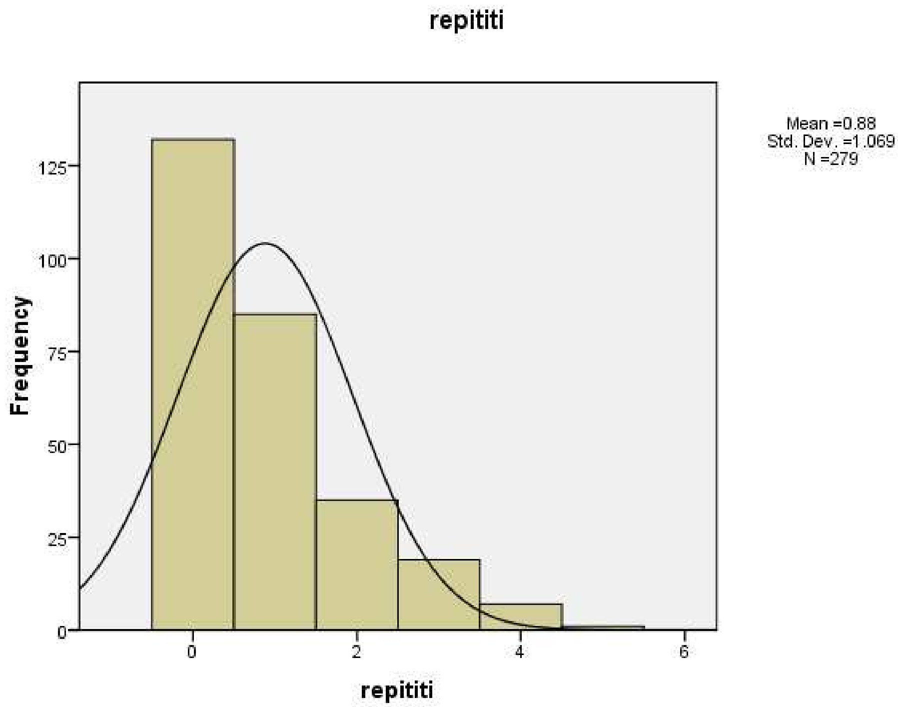

Figure 21 Frequency histogram for variable repettions

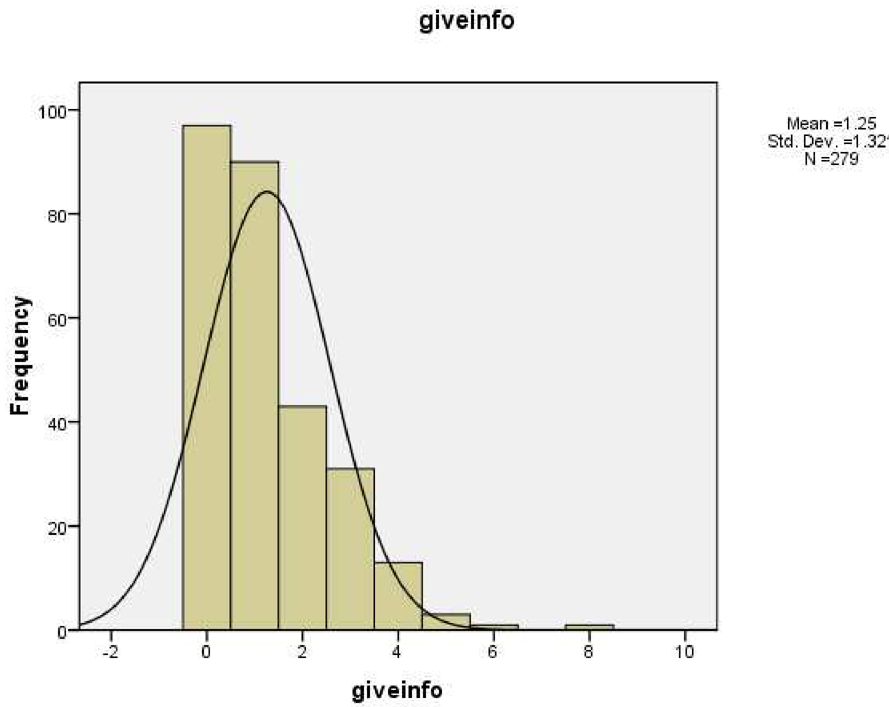

Figure 22 Frequency histogram for variable give information

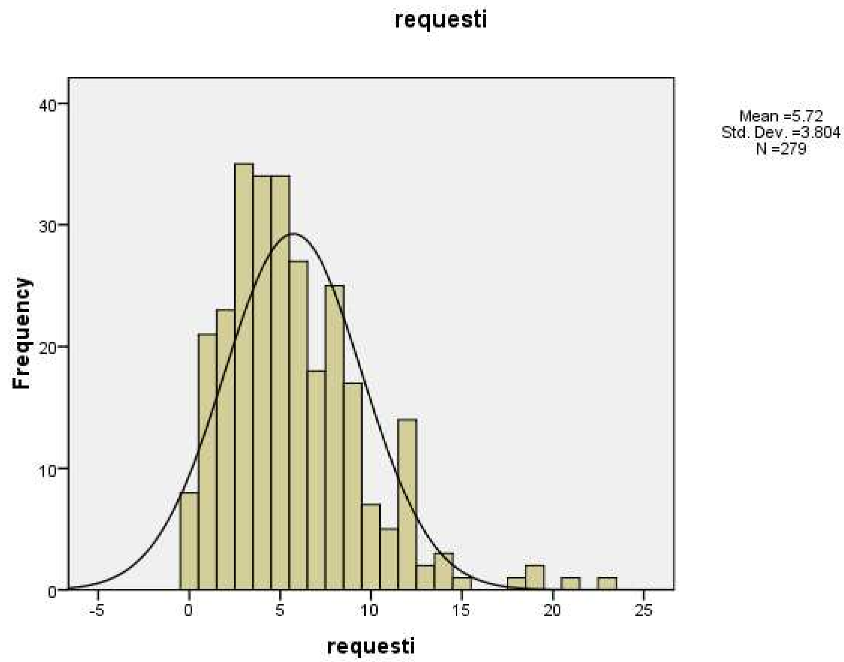

Figure 23 Frequency histogram for variable request informaiton

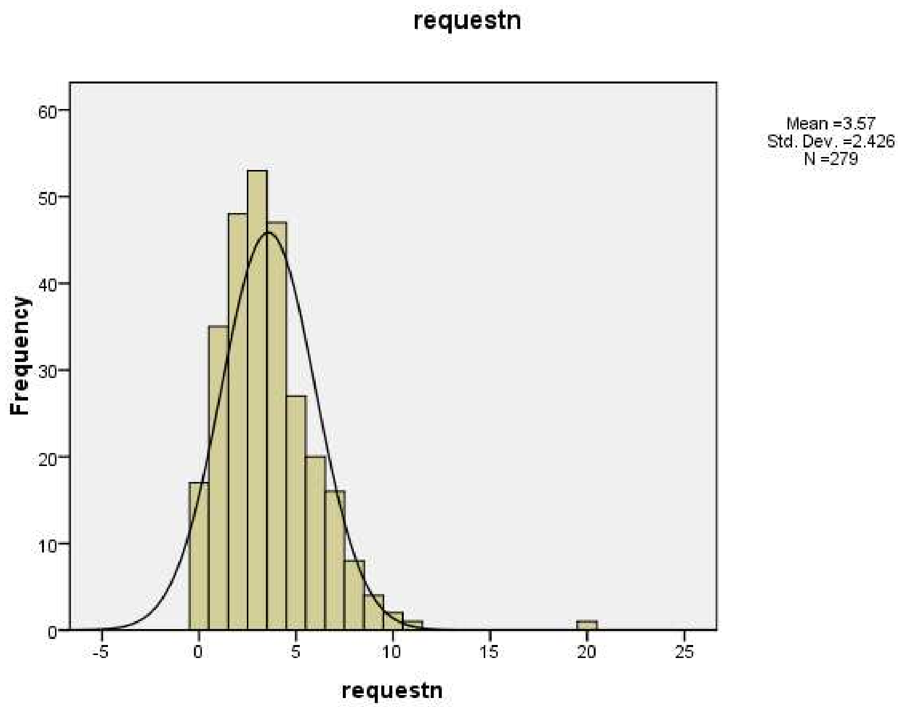

Figure 24 Frequency histogram for variable request new task

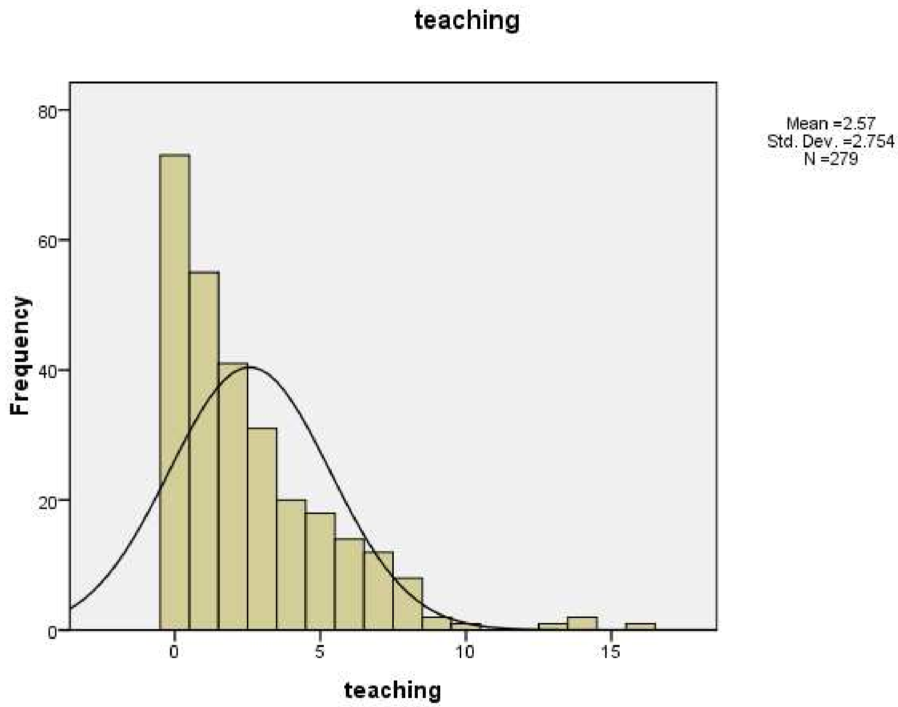

Figure 25 Frequency histogram for variable teaching

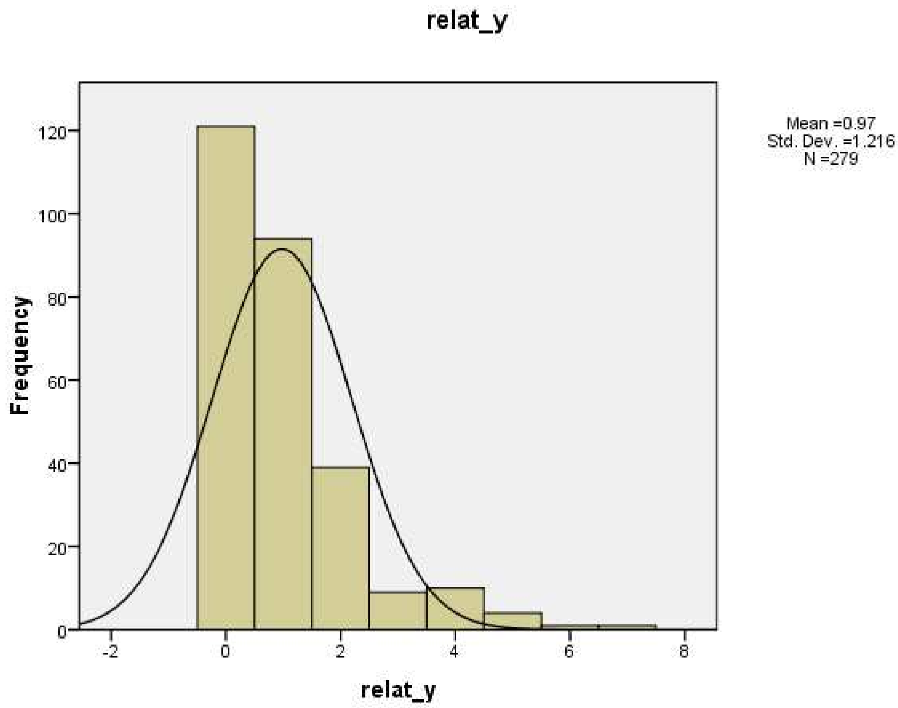

Figure 26 Frequency histogram for variable related question with response yes

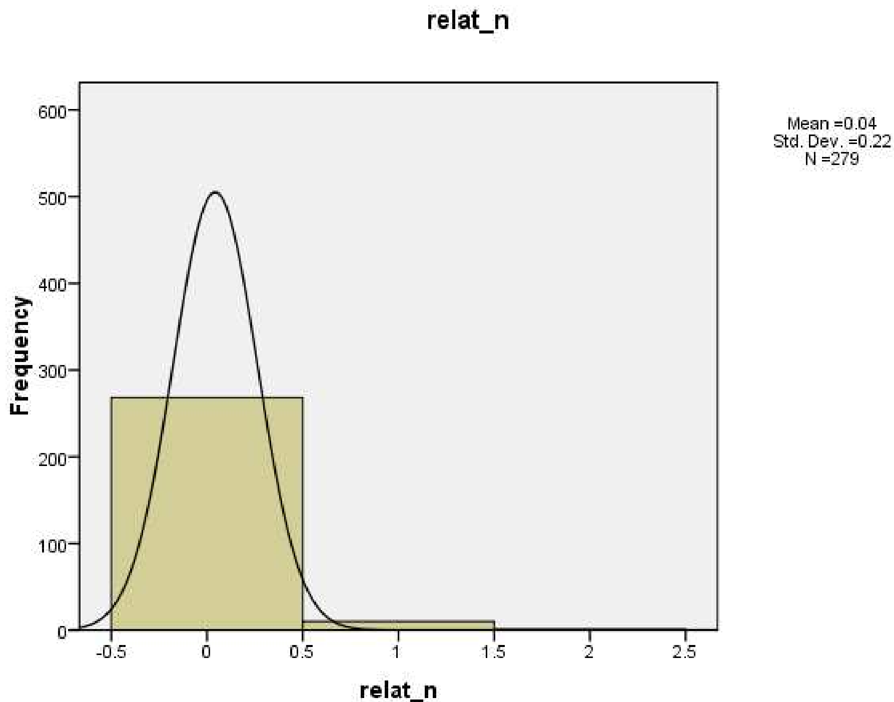

Figure 27 Frequency histogram for variable related question with response no

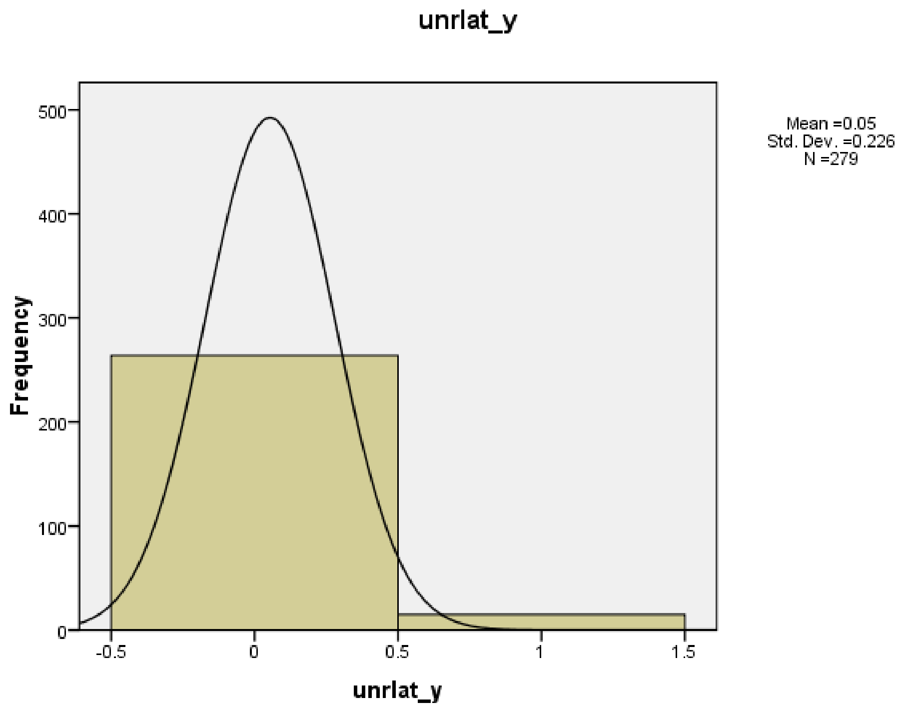

Figure 28 Frequency histogram for variable unrelated question with response yes

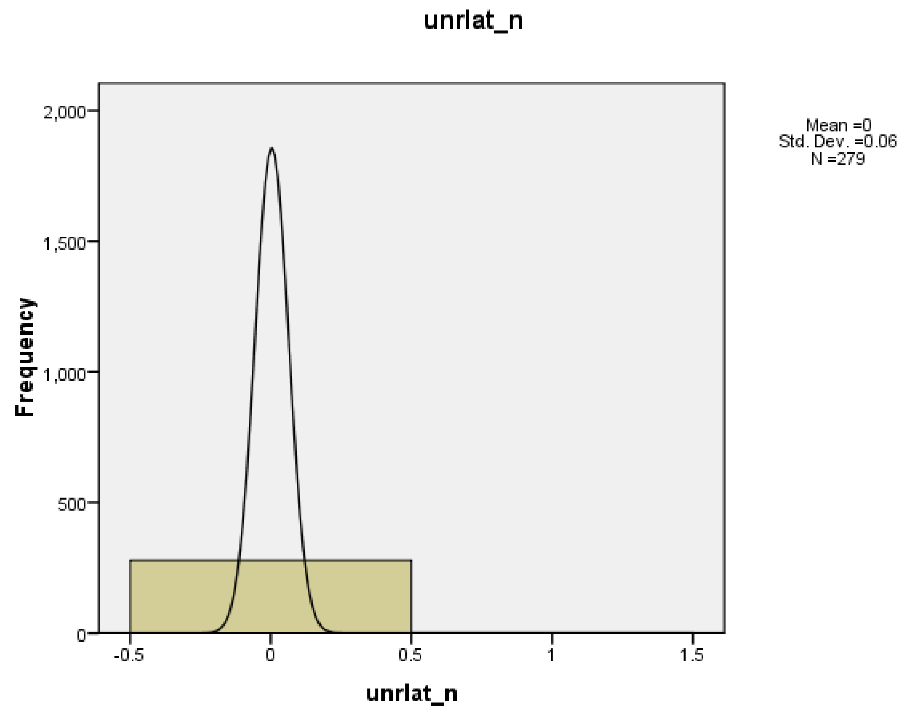

Figure 29 Frequency histogram for variable unrelated question with response no

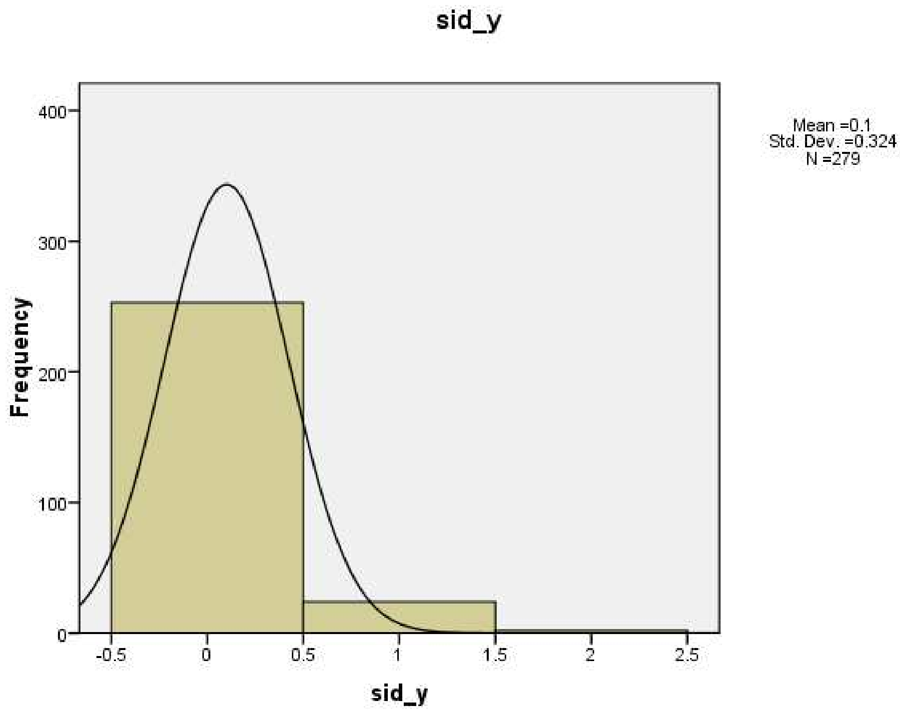

Figure 30 Frequency histogram for variable side conversation with response yes

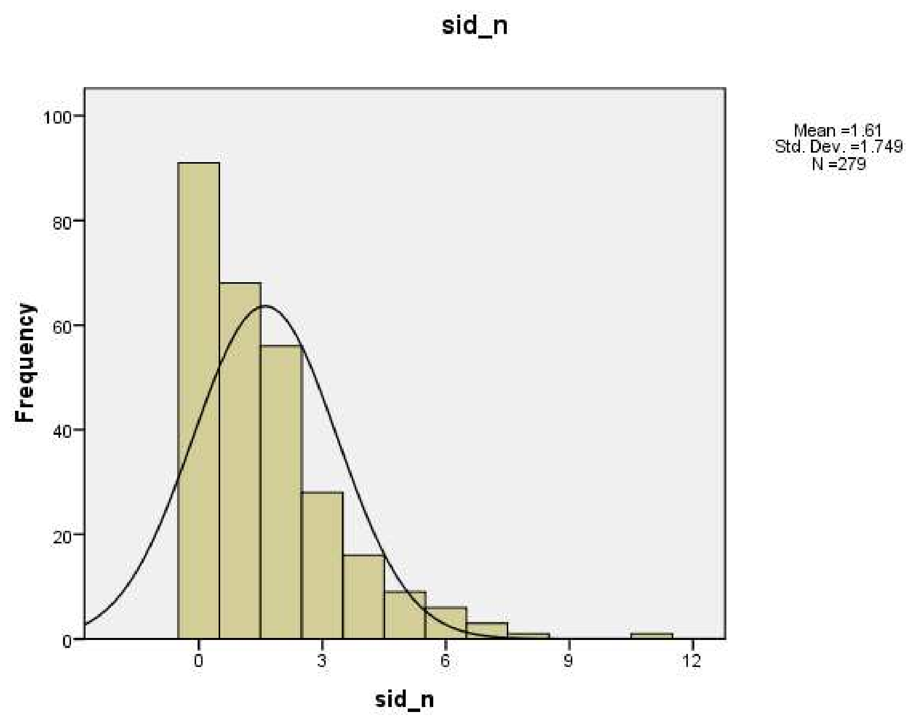

Figure 31 Frequency histogram for variable side conversation with response no

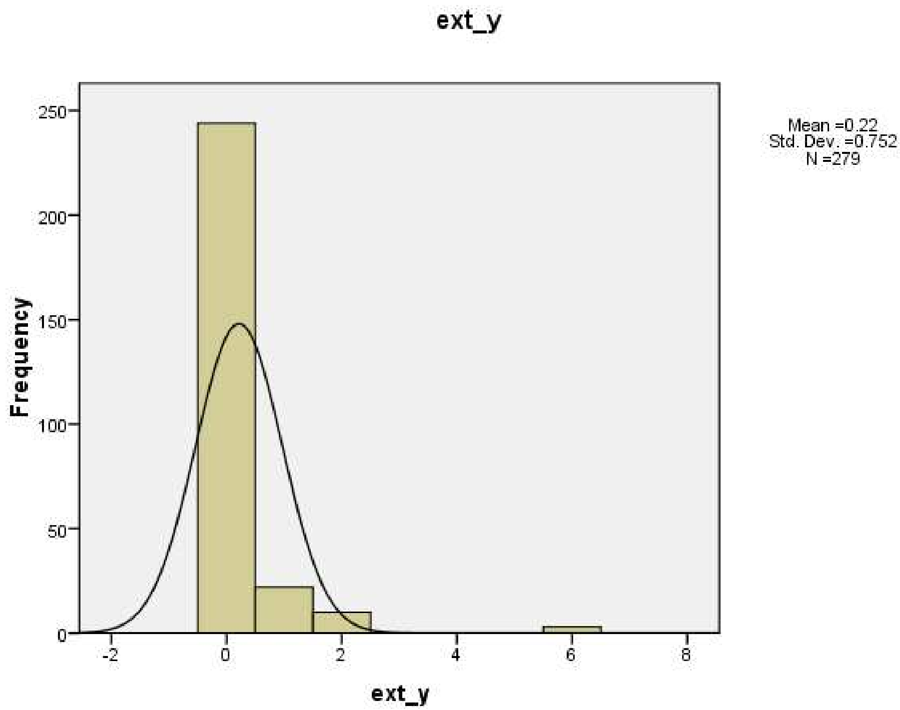

Figure 32 Frequency histogram for variable external interruption with response yes

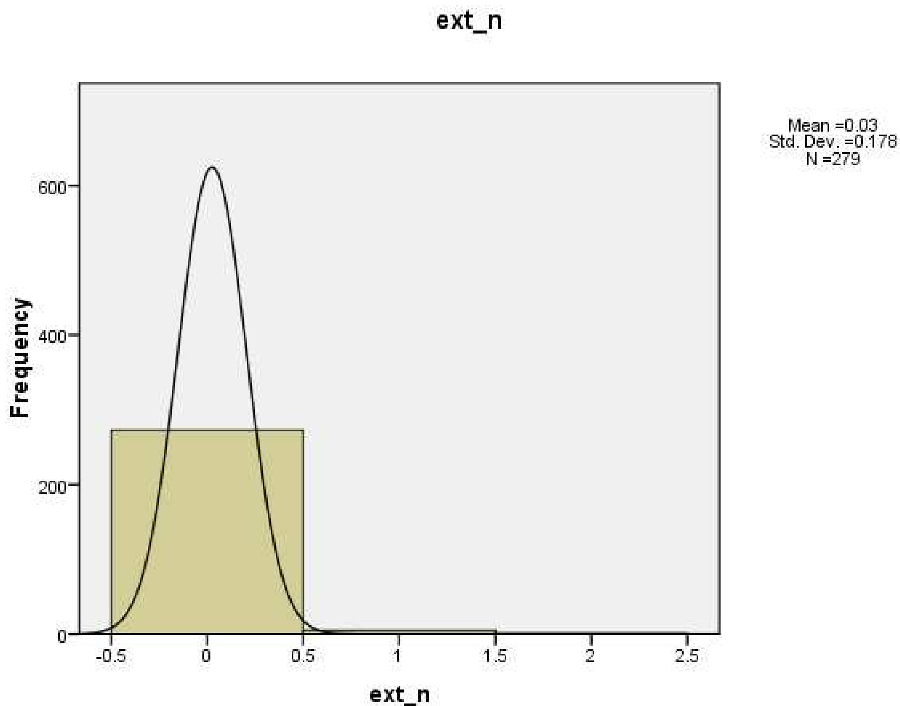

Figure 33 Frequency histogram for variable external interruption with response no

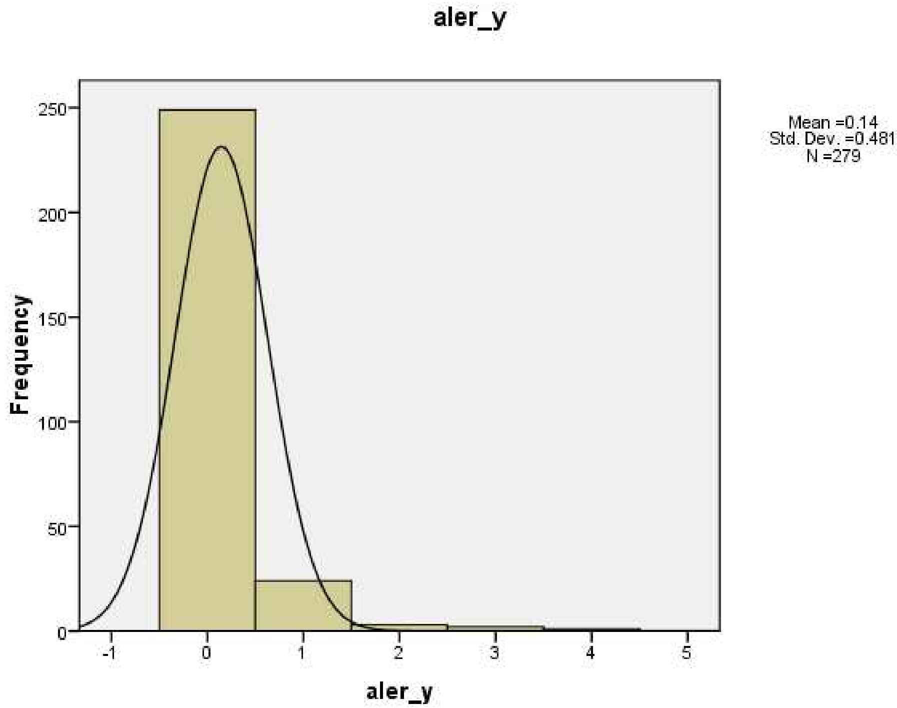

Figure 34 Frequency histogram for variable alert with response yes

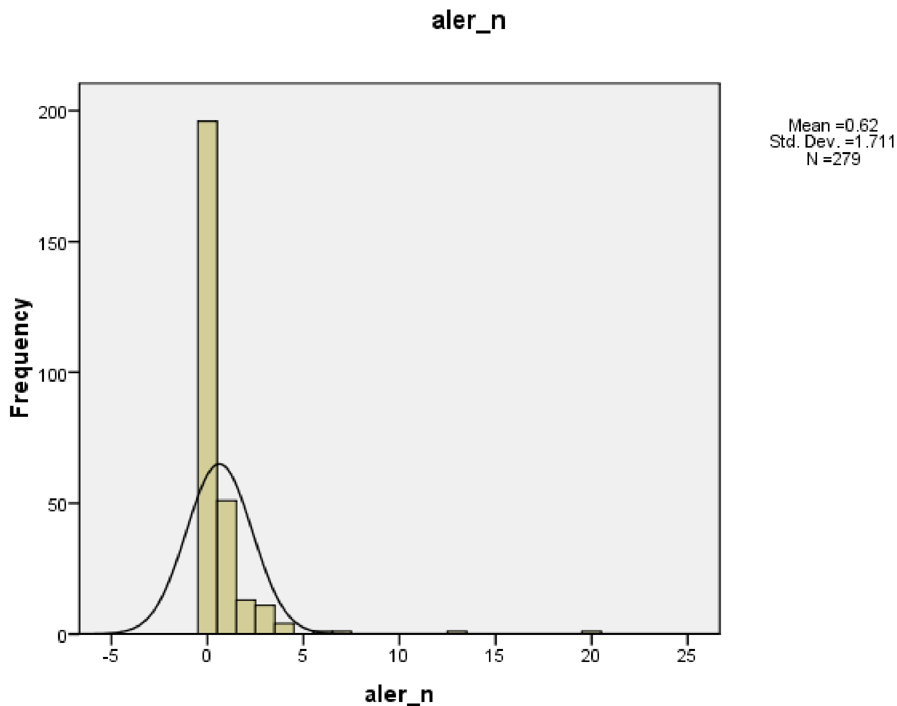

Figure 35 Frequency histogram for variable alert with response no

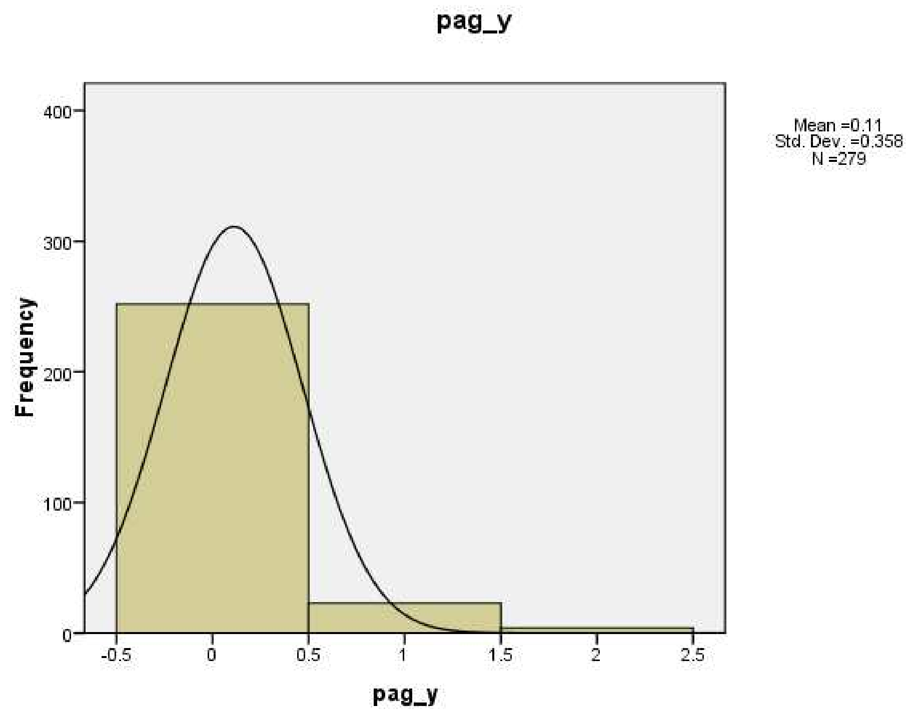

Figure 36 Frequency histogram for variable pager with response yes

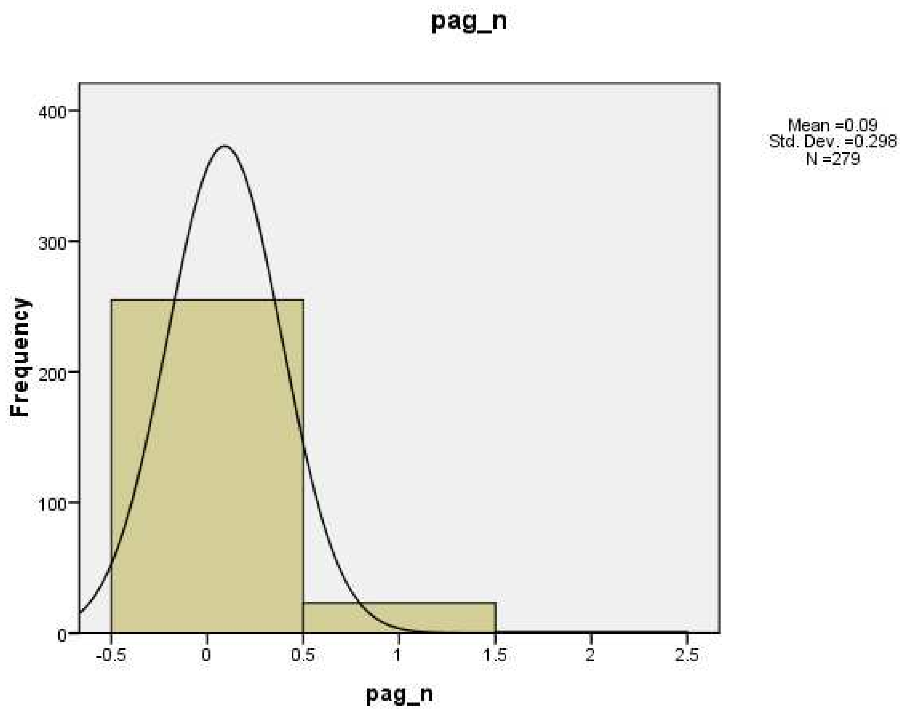

Figure 37 Frequency histogram for variable pager with response no

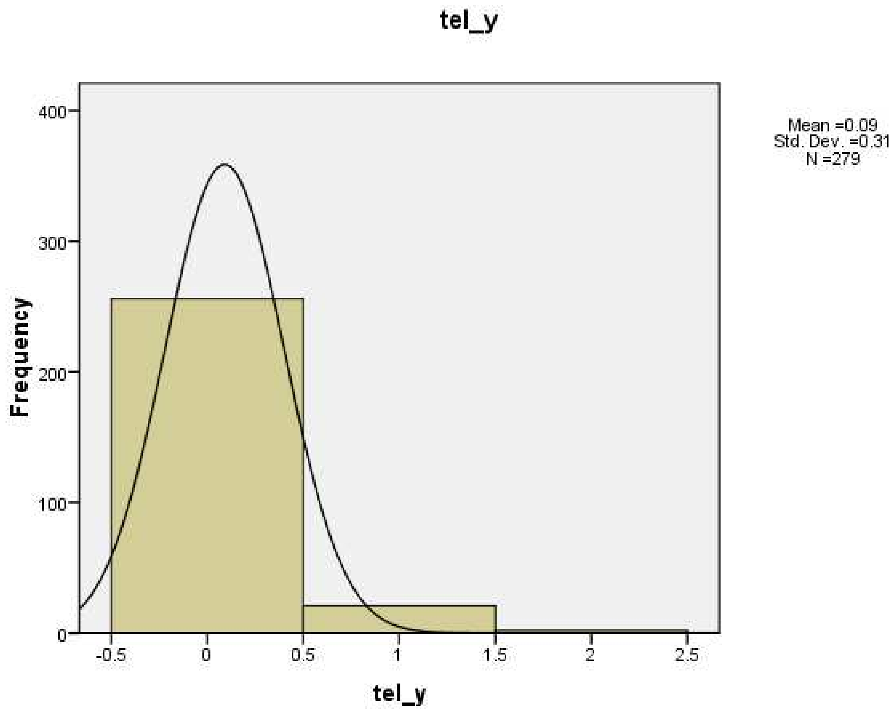

Figure 38 Frequency histogram for variable telephone with response yes

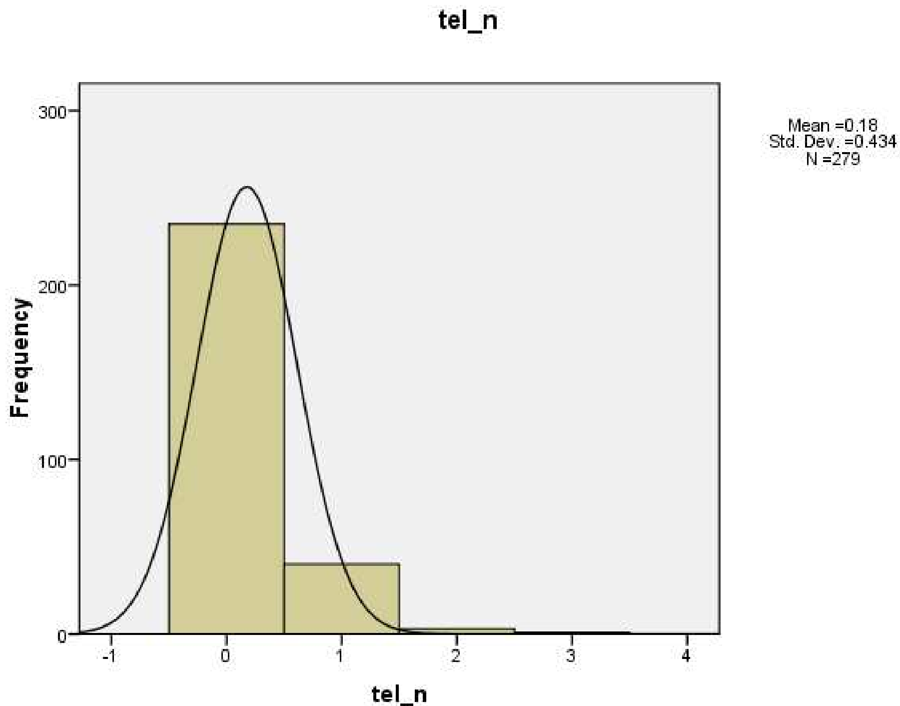

Figure 39 Frequency histogram for variable telephone with response no

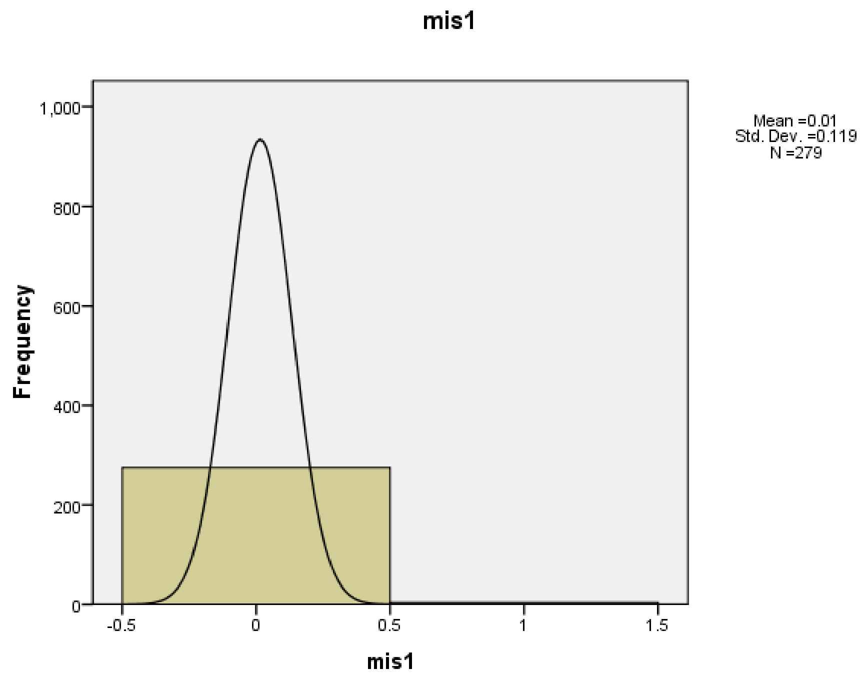

Figure 40 Frequency histogram for variable LP correct themselves

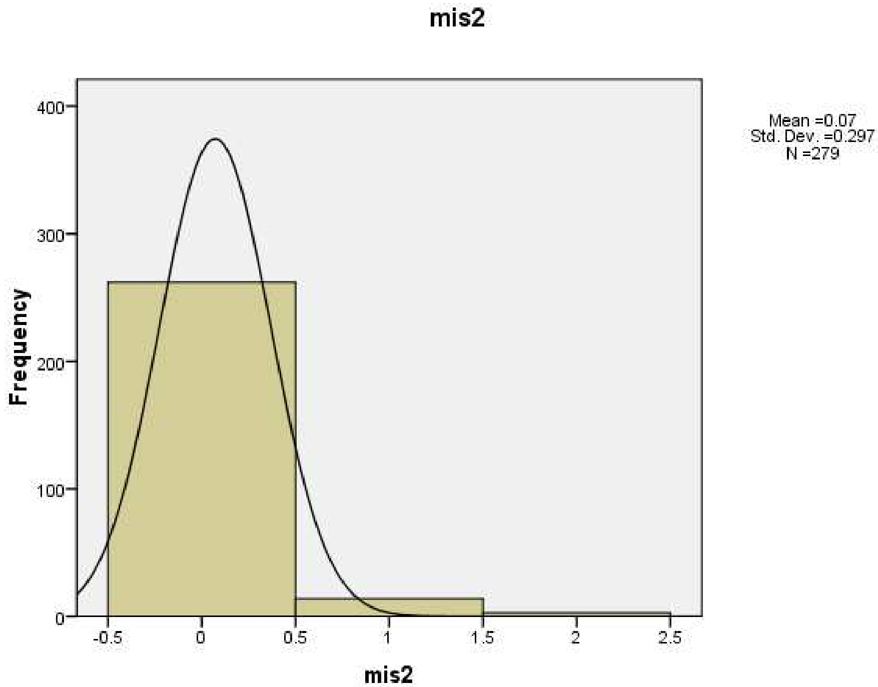

Figure 41 Frequency histogram for variable LP corrects tea members

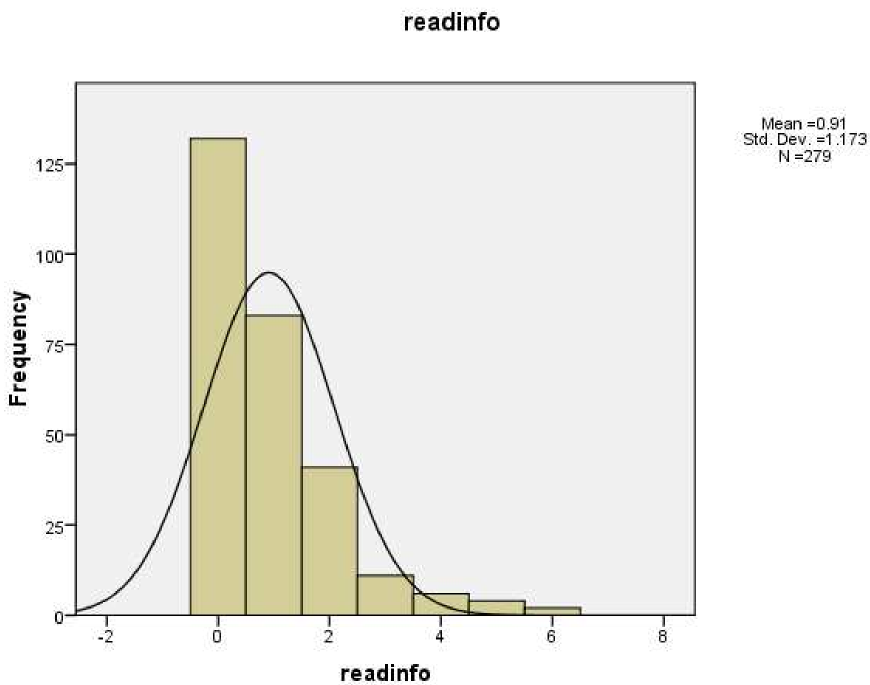

Figure 42Frequency histogram for variable LP read informaiton

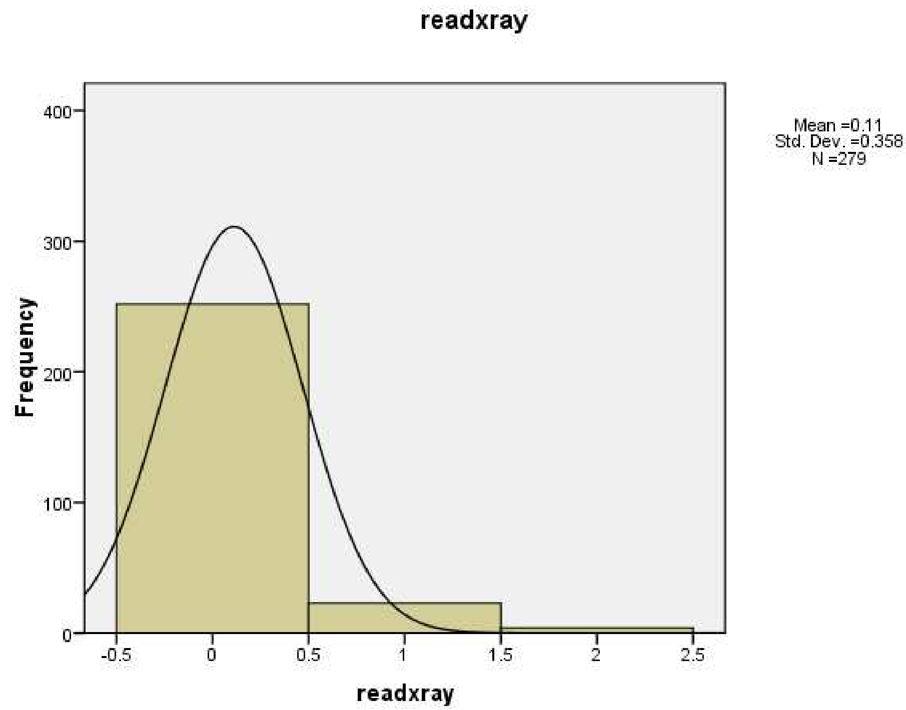

Figure 43 Frequency histogram for variable LP reads imaging

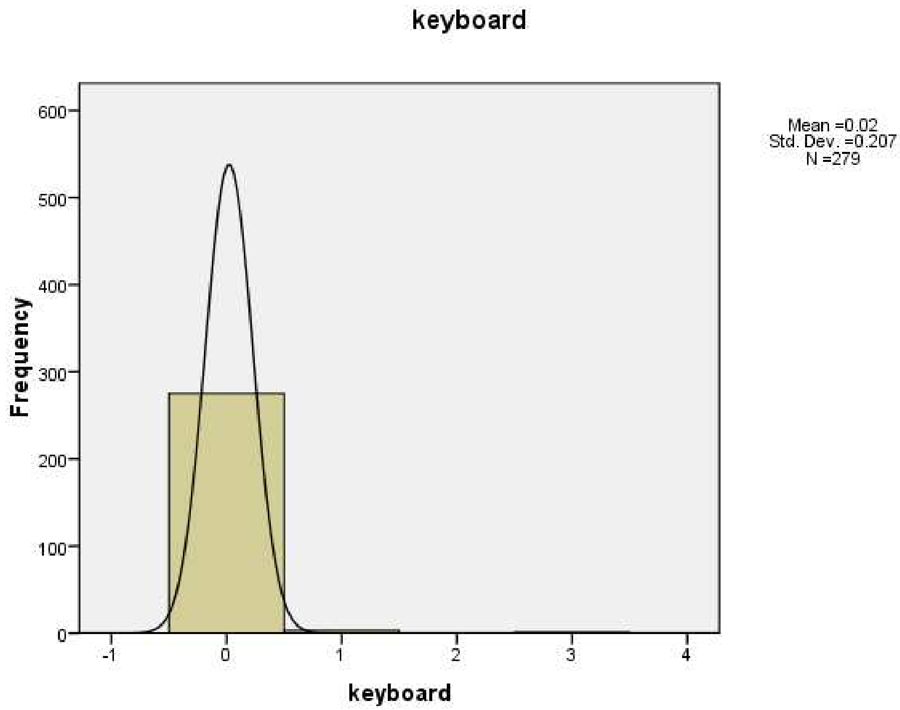

Figure 44 Frequency histogram for variable LP uses keyboard

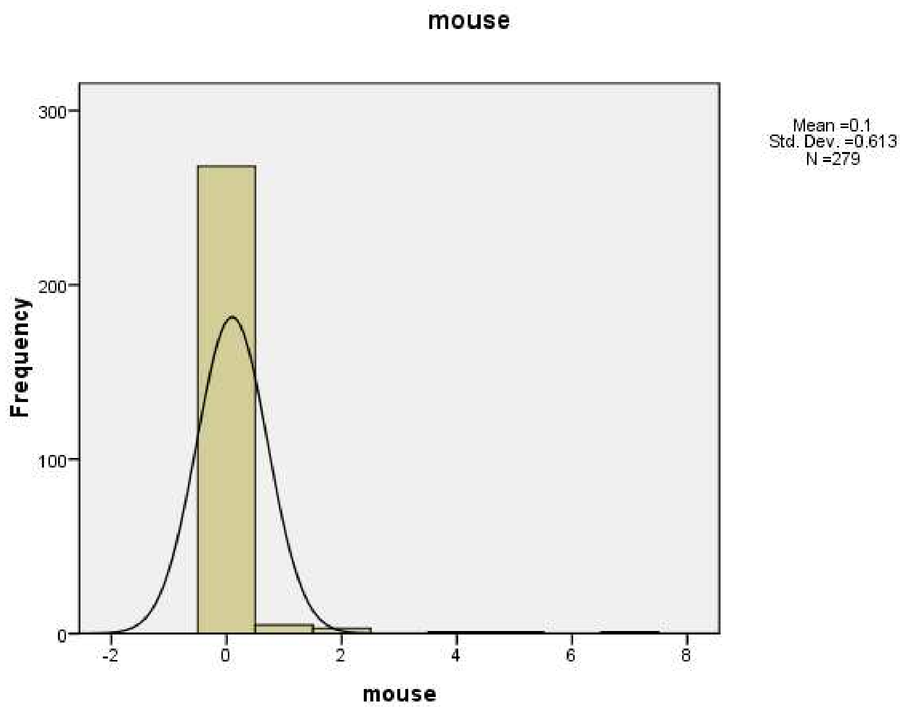

Figure 45 Frequency histogram for variable LP uses mouse

VITA

Saif Khairat was born in Cairo, Egypt on August 23, 1983, the son of Dr. Sherif Khairat and Dr. Azza Karar. Saif has spent over a decade in the United States of America acquiring more than just academic knowledge; an opening experience to the various faces of life. Many long, quiet nights and many more odds faced in this long, life-changing journey however; nothing could have been probable without the support, patience and love from the three greatest pyramids of his life namely, his father, mother, and sister Salma Khairat. To whom Saif will eternally be grateful and thankful.

Mr. Khairat is receiving a PhD in Health Informatics, supervised by Dr. Yang Gong, from the Informatics Institute at the University of Missouri. During his master's degree in Computer Science and under the supervision of Dr. Chi-Ren Shyu, he designed and developed a clinical content tracking system by bridging Database Management Systems and web applications. In 2007, his commitment to improving healthcare outcomes solidified when his late grandfather, Ali Hasan, suffered a serious medical error. Mr. Khairat's research focuses on the areas of patient safety and medical errors by closely studying human processes and human-computer interactions. His computational, teaching, and research skills combined with his understanding of clinical workflows and settings provide him with a unique set of attributes, which will facilitate his mission towards significantly contributing to science and society.

"*Be patient (in adversity); for, verily, God will not let the reward of the righteous be wasted.*" *The Holy Quran*, Chapter 11, Verse 115.