COLLABORATIVE DEVELOPMENT OF MEDICAL DEVICES: QUALITATIVE STUDY OF COMMUNICATION BETWEEN PHYSICIANS AND ENGINEERS

by

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Abstract

The importance of collaboration between physicians and engineers on improving the medical devices and patient safety is highly recognized. Previous studies found communication as an important component to interdisciplinary collaboration, however, maintaining an effective interdisciplinary communication can be challenging. With scarce literature on investigating the interaction between physicians and engineers, this study focuses on exploring the communication experiences of these two professional groups who have worked together collaboratively on medical devices. To better understand their challenges and facilitators, this research identifies six pairs of engineers and physicians who have worked together for years. All six cases, twelve engineers and physicians in total, are interviewed separately under qualitative case study method. The result of thematic analysis discovers three main categories: building relationship, team members quality, and communication techniques. The findings show that team members quality such as interest and dedication can help build strong relationships. Defining clear expectations at the beginning of the projects as well as sharing workload seem to improve relationships and foster communication. Other techniques contributing to effective communication include continuous feedback and face to face meetings. With a more careful analysis of findings, a model of personal and contextual factors with an emphasis on their interrelationship is suggested. Reviewing communication practices in all six cases illustrates that the benefits of collaboration overweigh the barriers. Thus, it is recommended that collaboration between physicians and engineers continue in the whole process of developing medical devices.

Lay Summary

Maintaining effective interdisciplinary communication can be challenging. For physicians and engineers working together on medical device development, communication is vital to the success of their collaboration. With the growth of interdisciplinary partnerships, exploring communication challenges and facilitators can foster successful collaboration. This study explores communication practices of six pairs of engineers and physicians who have worked together for several years. By examining their communication experiences through qualitative analysis, this study seeks to identify ways to improve communication. The findings of this study suggest that building relationships, team member qualities, and communication techniques are contributing factors to effective communication.

Preface

This thesis is an original, unpublished work by the author, Aida Hassani. I was primarily responsible for the concept, data analysis, and composition of the manuscript. My research committee, overseen by my research supervisor Dr. Sandra Jarvis-Selinger, comprised of Dr. Sayra Cristancho, Dr. Laura Nimmon, and Dr. Antony Hodgson. They provided expert advice regarding all aspects of my thesis including several iterations of manuscript revisions.

The UBC Behavioural Research Ethics Board approved this study on August 30, 2018 under the certificate number of H18-01165.

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Dedication

"To the patient who suffered an adverse consequence in surgery as a result of miscommunication"

Chapter 1: Introduction

Literature recognizes the importance of interdisciplinary collaboration between physicians and engineers in designing effective medical devices and improving patient safety. It also highlights the communication challenges that these two professional groups experience when working together. Having said that, the empirical studies have mainly focused on interdisciplinary communication and collaboration between physicians and other healthcare professionals or disciplines. The interaction between physicians and engineers has been overlooked or studied very little. In response, this research proposes to study the communication experiences of these two groups -physicians and engineers- to explore their perspectives on their communication, identify the barriers and facilitators, and investigate their approaches to address communication challenges. In this chapter, I review the previous studies on the importance of communication in both healthcare and medical device development. I then define the goals of the project, and explain the adopted methodology to complete this thesis. Finally, I cover the structure and design of this study.

1.1 Background

Medical device risks and errors endanger patient safety. In the report "To Err Is Human: Building a Safer Health System", the Institute Of Medicine (IOM) reported that between 44,000 to 98,000 people die each year in the United States because of medical errors. Thus, the report recommended a national initiative should be undertaken to reduce medical errors (Kohn, Corrigan, & Donaldson, 2000). Therefore, incorporating patient safety into the development of medical devices is critical to every healthcare and medical device project (Emslie et al., 2002; Kramer et al., 2014; Canada's health care system, 2017).

According to the IOM report (2000), sources of medical error include the decentralized and fragmented state of health care delivery systems, barriers to accessing complete patient data, and lapsed attention to the prevention of medical mistakes. Thus, the issues are multidimensional. The IOM suggested several ways to enhance health care and patient safety. These suggestions included the establishment of interdisciplinary training teams, programs, and collaboration with a focus on designing safe devices. Working collaboratively improves health care (Drinka & Clark, 2000) and represents an essential element of both patient safety and productivity at health research organizations (Makary et al., 2006). Recent findings on this subject emphasize that strong collaboration produces improved health care and patient safety results (Morley & Cashell, 2017).

While communication has been identified as a fundamental determinant of effective collaboration (Ng, 2011; Huggett et al., 2011; Morley & Cashell, 2017; Johnson, 2019), research shows that medical error represents the most salient factor in failed communication (Brennan et al., 1991; Wilson et al., 1995; Kohn, Corrigan, & Donaldson, 2000; Alvarez & Coiera, 2006). Furthermore, ineffective communication has been identified as the most common reason for medical errors that endanger patient safety (Murphy & Dunn, 2010). From 1995-2004, breakdowns in communication were cited as the most prevalent cause of preventable deaths (O'Daniel & Rosenstein, 2008).

Studying the connection between medical device development and interdisciplinary collaboration represents a growing area of inquiry in medical research. The necessity of involving engineers who "play an essential role in research and development of medical devices" (Cummins et al., 2018, p. 435) as well as physicians as users of medical devices is highly recognized in studies (Shah & Robinson, 2006; Chatterji et al., 2008; Yoda, 2009, 2016). Prior analysis of interdisciplinary collaboration practices revealed that collaboration between physicians and engineers confronted many challenges (Reid et al., 2005; Ng, 2011; Yoda, 2009, 2016; Cummins et al., 2018). These challenges were principally attributed to the limited exposure of each professional group to the experiences of the other, along with the corresponding knowledge deficits. Engineers working in the medical device field do not understand everything about the health care system because they were educated at engineering schools outside of a hospital-based context (Reid et al., 2005; Ng, 2011). Also, there is no exposure to mathematical and physics topics for medical students, as well as no training programs helping professional doctors to understand the engineering concepts behind the medical devices (Ng, 2011).

While there is growing literature on exploring the interdisciplinary research between physicians and other disciplines, the collaboration between physicians and engineers is overlooked (Cummins et al, 2018). The existing research shows some of the emerging factors that contribute to successful collaboration between physicians and engineers, however there is little empirical research on examining communication practices between engineers and physicians. In response, this research proposes to study the communication experiences of the two groups -physicians and engineers- to explore their perspectives on communication, identify the barriers and facilitators, as well as their approaches to address communication challenges.

1.2 Purpose of this thesis

The specific objectives of this thesis are:

a) Exploring topics that arise in communication practices between engineers and doctors who work collaboratively together by interviewing both engineers and doctors from each team.

b) Addressing the communication challenges and facilitators, along with their incorporated techniques to overcome hurdles.

By investigating engineers' and doctors' experiences of interdisciplinary communication, this research sheds light on the topics that arise in communication practices. In addition to confirming the presence of communication patterns consistent with other research findings, this study utilizes its data to identify new issues and to explore alternative ways to improve communication.

1.3 Study design and dataset

I completed this research under the qualitative case study methodology. Qualitative approaches are most applicable when the researcher aims to explore the subjective views of the participants (Sutton & Austin, 2015). The objective of qualitative inquiry is to seek answers through the analysis of descriptive data, observation, interview, writing, and reflection (Hammarberg, Kirkman, & de Lacey, 2016). Five common approaches to qualitative research include narrative study, grounded theory, ethnography, case study and phenomenology (Creswell, 2007). Each style carries advantages and disadvantages. All approaches could potentially be suitable designs for my research, however I selected a 'case study' approach in order to answer the 'what' (What arises …?) and 'how' (How can we address …?) (Yin, 2018).

There were twelve participants in total: six engineers and six physicians. The participants were recruited from teams that have been working together collaboratively. Each engineer and doctor were defined as one case for this research (six cases in total: three were located in Canada and three in the United States) and each individual was interviewed separately. This study was designed to investigate communication experiences of professional participants. Choosing professional engineers and doctors who have had years of collaboration experiences was intended to maximize the opportunity of exploring contributing factors to what works best or not best in their communication.

Thematic analysis was used to identify, analyze and report repeated patterns of meaning, (i.e. themes that were identified across the data set) (Braun & Clarke, 2006). I completed the coding through the combination of: a) traditional method (readings, taking notes, and sorting and organizing the coding through colored sticky notes) and b) a computerized one through the utilization of the qualitative software program, Nvivo (Maher et al., 2018). I conducted this initial coding based on the predetermined categories derived from the literature review and pilot study I completed for one of the courses at UBC (Hassani et al., 2019). The result of this analysis revealed three main themes: building relationship, team members qualities, and communication techniques. Each themes and their sub-themes are described in chapter four (Results).

1.4 Structure and organization of thesis

This thesis is organized into five main chapters. In the introduction chapter (Chapter One), I have provided a short summary of my thesis design and structure. In the background I highlight that communication is an important factor to successful collaboration, yet it is also recognized as a hurdle to collaboration. Thus, the objective of this study is to explore the perspectives of doctors and engineers on communication, as well as to learn their approaches to achieve effective communication. In literature review (Chapter Two), the current research and studies related to my thesis topic have been described. I have looked at the importance of interdisciplinary communication from the healthcare standpoint, as well as between engineers and physicians. Then, based on my knowledge from retrieved studies, I review the reported factors that contribute toward better collaboration and communication. In the methodology chapter (Chapter Three), I consider the research questions and describe the undertaken qualitative case study method. Following that, I examine the conceptual phase, data collection and type of analysis. In the result chapter (Chapter Four), I report the findings of this study based on the emerged themes along with the verbatim quotations from research participants. In the discussion and conclusion chapter (Chapter Five), I take into account the previous research and findings of this study to describe my own refined understanding of communication.

Chapter 2: Literature review

In this chapter, I explore the current literature about the communication between engineers and physicians during their collaboration in developing medical devices. To better understand the importance of communication experiences between these two professional groups, the research took me to look further in literature and investigate the risks and benefits of medical devices and patient safety. I then review the importance of communication and collaboration in both healthcare and medical technologies, and examine the current challenges and suggested solutions. At the end of this chapter, I present a short summary describing the aims of this study along with my research questions.

2.1 Medical devices: risks and benefits

In the world of interdisciplinary collaboration, the result of combining different scientific disciplines has turned many impossibilities in medical health science into possibilities (Siposs, 1980). The development of medical devices is one of the greatest outcomes of the symbiosis of engineering and medicine disciplines. Medical devices are "a diverse group of products used to enhance the quality of patient care by restoring function, and aiding in the diagnosis, prevention, treatment and management of diseases and disabilities" (Snowdon, Zur, & Shell, 2011, p. 5). These devices are well recognized for all their benefits for modern healthcare delivery (Snowdon, Zur, & Shell, 2011; Blandford, Furniss, & Vincent, 2014). Research has shown that in many clinical cases, incorporating medical devices as part of a patient's treatment is necessary (Blandford, Furniss, & Vincent, 2014; Zens, Fujita, & Windeler, 2015). Moreover, medical devices can help the patient's care by performing the job precisely, quickly and efficiently (Siposs, 1980).

Besides all the benefits that these life-saving technologies have brought to patients and healthcare (Cummins et al., 2018; Wamble, Ciarametaro, & Dubois, 2019), medical devices can also cause some risks for patients (Grober & Bohnen, 2005; Panesar et al., 2011; Alemzadeh et al., 2013; Blandford, Furniss, & Vincent, 2014). In their study on the impact of medical technology on patient's safety, Emanuel and her colleagues (2011) have pointed out that "poor design, poor maintenance and implementation, inadequate training, misuse of equipment and over reliance on technology" can lead to technology compromising safety (p. 3). To mitigate risks posed by medical devices, the government of Canada (2019) has published a report on improving safety, quality, and effectiveness of medical devices. In their report "Health Canada's Action Plan on Medical Devices", they have emphasized the importance of monitoring the devices, strengthening regulations, and taking mandatory actions to improve the reporting of medical device incidents. This highlights the significance of incorporating patient safety in designing and developing medical devices (Kramer et al., 2014).

2.2 Patient safety

Patient safety has been at the centre of attention in every healthcare system and the focus of many research projects (Emslie et al., 2002). In Canada, improving patient's safety has been one of the most significant aspects of their health care system (Canada's health care system, 2017). Patient safety practices have been defined as those that reduce the risk of adverse events related to exposure to medical care (Shojania, et al., 2001). It depends not only on the knowledge, skills and behaviors of the front line workers, but also on how the workers collaborate together (WHO, 2008, p 108).

In 1999, the Institute of Medicine (IOM) announced a serious concern in health care regarding patient safety caused by medical errors (Kohn, Corrigan, & Donaldson, 2000). The IOM's report systematically addressed patient safety in the United States, a report which aroused an enormous public response and brought national focus to this important issue (Ilan & Fowler, 2005; Baker, Day, & Salas, 2006). In their report, To Err Is Human: Building a Safer Health System, the IOM stated that as many as 98,000 people die annually in the United States as the result of medical errors. Consequently, the IOM called for a national effort to make health care safer.

The IOM's report emphasized that multiple factors contribute to the occurrence of medical error (e.g. decentralized and fragmented nature of the health care delivery system, lack of access to patients' complete information, limited attention on the 'prevention' of medical errors). Therefore the issues are complex and multifaceted. The IOM issued several recommendations to improve the quality and reliability of health care and patient safety. Some of IOM's recommendations included safety systems design, establishing interdisciplinary team training programs, and enhancing teamwork and collaboration. These suggestions have also been emphasized by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) (O'Daniel & Rosenstein, 2008). The JCAHO requested that hospitals include collaborative work and communication among their health care staff as their top practices to ensure patient safety (Baker, Day & Salas, 2006).

More research in this area reiterates that strong collaboration can lead to improved health outcomes (Morley & Cashell, 2017). Interdisciplinary collaboration is widely promoted as a way of enhancing health care (Drinka & Clark, 2000) and it has been considered an integral part of patient safety, as well as an essential component of health research organizations (Makary et al., 2006; Baker, Day & Salas, 2006). This shows the maturity of the science of safety to include collaboration and communication breakdowns, among other errors such as diagnostic errors, device-errors, poor judgment, and inadequate skills, as being directly involved in threatening patient safety (Makary & Daniel, 2016).

2.3 Collaboration and communication in health care

Historically, physicians, nurses, and other health care professionals have operated as distinct parts (Knox & Simpson, 2004). This is mainly due to the fact that health care members often come from separate disciplines and different educational programs (Baker, Day & Salas, 2006). Since the IOM's report, teamwork among different health care workers related to improving patient safety have been getting more attention in healthcare. Patient safety, a topic that had been little understood and even less discussed in care systems, became a major focus of health care professionals and leaders (Leape & Berwick, 2005; Groszek, 2010). Moreover, dramatic advances in safety practices, including increased training on teamwork and safety, were implemented to improve patient safety (Leape & Berwick, 2005).

While the situation has changed since the IOM's report, the efforts have affected safety at the margin and their overall impact in US statistics is hard to see (Leape & Berwick, 2005). According to O'Daniel and Rosenstein (2008), the Joint Commission ranked medical errors number five on the National Centre for Health Statistics list of the top 10 causes of death in the United States. More recent studies report much higher numbers and rank medical errors as the third leading cause of death in the USA, placing medical errors right behind heart disease and cancer (Makary & Daniel, 2016).

Research reports, among the errors, ineffective communication is the key factor in medical error

(Brennan et al., 1991; Wilson et al., 1995; Kohn, Corrigan, & Donaldson, 2000; Alvarez & Coiera, 2006). Moreover, communication breakdowns are considered the most common cause of medical errors, threatening patient safety (Murphy & Dunn, 2010). During 1995-2004, communication failures are described as the most common root cause of preventable deaths (O'Daniel & Rosenstein, 2008). The U.S. Patient Safety Network, Agency for Healthcare Research and Quality (2019) report that the underlying reasons for the underdeveloped health care safety culture are complex, and poor collaboration and communication are among main factors.

While teamwork and communication are effective elements on patient safety (Beckett & Kipnis, 2016), collaborative practices and effective communication are difficult to achieve (Yoda, 2009; Ng, 2011). Despite the growing body of research in this area, there is little understanding of the complex nature of collaboration and its determinants (Reeves & Lewin, 2004). In fact, the science of collaboration and teamwork is still evolving in health care (Baker, Day & Salas, 2006). Within this limited understanding, communication has been identified as a fundamental determinant of effective collaboration (Ng, 2011; Huggett et al., 2011; Johnson, 2016; Morley & Cashell, 2017).

Communication can take on various forms, such as verbal, nonverbal, direct or indirect, but to collaborate effectively, one has to communicate with the other and understand what the other means. Spending time together (though not necessarily in each other's physical presence) and conveying accurate messages to the other collaborator(s), as well as making sure that the messages are accurately received contribute to effective collaboration. Additionally, appreciating each other's perspectives and, working together on common goals similarly contribute to effective collaboration (Thayer-Bacon & Pack-Brown, 2000).

According to Morley and Cashell (2017), communication is "affected by the ability to communicate one's role, communicate efficiently and constructively, and communicate in a way that develops other determinants of collaboration such as respect and trust" (p. 212). Understanding each other and mutually communicating through a shared language are also important in effective collaboration. Thayer-Bacon and Pack-Brown (2000) have highlighted this in their definition of 'collaboration':

> "…collaboration is the intellectual and emotional interaction that takes place between diverse people who are in a changing relation with each other and are able to mutually communicate through an accurate and shared verbal and nonverbal language; therefore, they are potentially able to influence each other." (p.51)

This all means that teamwork among different health care workers, along with interdisciplinary collaboration, coordination, and communication in health care are essential factors in patient safety (Baker, Day & Salas, 2006).

2.4 Collaboration and communication in medical technology

Within the context of collaboration between healthcare workers, research shows that collaboration between physicians and engineers is beneficial in improving patient safety and developing effective medical devices (Ponte et al., 2010; Yoda, 2016). Such interdisciplinary collaboration is of high importance as it brings in clinical knowledge, expertise, and data, as well as contemporary clinical issues, into designing medical devices. This collaboration has shown to help with maintaining the quality and quantity of biomedical engineering research outputs, which proves especially beneficial in developing effective medical devices (Ponte et al., 2010; Yoda, 2016; Cummins et al., 2018).

To design better and safer medical devices, research shows that physicians and engineers need to work effectively together. This means that rather than designing in isolation, these two professional groups should work more closely together in collaborative team environments (Bennet, 2014). A collaborative environment can maximize the opportunity of creating a ‘collective knowledge base’ when engineers and clinicians combine and gather their ‘respective knowledge and experience’(Chekan, Whelan, & Feng, 2013, p. 2).This togetherness ultimately helps to design an effective medical device helpful for both clinicians and patients.

Moreover, Bennet (2014) has found that each group’s ability complements the other and helps with successful collaboration. For example, physicians always need to modify and adapt their explanations to patients who come with different knowledge and educational backgrounds. This experience enables physicians to be good teachers in collaborating with engineering or other disciplines. On the other hand, engineers’ education and experience prepare them to manage the overall project with consideration for both the timeframe and the financial aspects of the project (Bennet, 2014).

In a collaborative research project between clinicians and engineers, Morschauser (2014) looked at the reports submitted to MedSun (Medical Product Safety Network) from hospitals, related to their medical devices malfunction. Comparing the quality of different reports, he found that hospitals with substantial collaboration between engineering and clinical staff were more efficient in reporting the medical device errors. However there was no reported connection to how this efficiency lessen medical errors. In their reports, they had included both clinical scenarios and engineering evaluations that were required to identify and repair the medical device errors. In this paper, Morschauser explained the factors that foster the communication between physicians and engineers. He stated that having regular safety meetings in which both of these groups can discuss the device-related information, as well as having a full-time engineer working with clinicians or vice versa are helpful. Including a simulation laboratory can also create a safe learning environment for clinical and biomedical staff to replicate a clinical scenario. Such simulation can be beneficial with identifying potential human errors. It also promotes communication and patient safety. Similarly, providing a simulation laboratory for biomedical engineers can create an environment for them to collaborate with the clinicians. Within this simulated environment, these two groups can replicate similar conditions around the device malfunction and determine the underlying causes which may prevent such errors in the future.

In addition to the above collaboration facilitators, Cummins and his colleagues (2018) highlight the importance of balancing the traditional power structure between physicians and engineers. In their study, poor collaboration practices between these two professional groups occurred on account of ineffective communication as the main factor. Communication issues, such as the introduction of perceived hierarchies or the independent execution of work without consultation, led to the creation of clinically irrelevant or useless devices. A specific type of ineffective communication happened when one group was perceived to be subordinate to the other. Physicians sometimes exert power over engineers in a manner that reduces the latter's autonomy of device design. When engineers act too independently, however, they produce devices that do not serve the specific clinical needs of the doctors. Thus, it is imperative that both groups collaborate equally with neither having power or authority over the other (Cummins et al, 2018). These examples highlight the importance of ongoing, reciprocal communication and the need to respect the collaborative partnership.

While the collaboration between physicians and engineers are beneficial, Cummins and his colleagues discussed that such collaboration often faces difficulties. In their empirical study, they examined the collaboration between these two groups and found that communication—bridging the gap between engineers and physicians —was the main challenge. The following section describes the difficulties that these two professional groups often face in their collaboration, followed by suggested solutions and discussions around communication.

2.4.1 Communication challenges in medical technology

- **Knowledge**: Lack of exposure to the other profession's practices in both groups and/or the lack of understanding their different knowledge bases can cause miscommunication. Many engineers who are currently involved in designing medical devices lack knowledge of complex health care processes as they were trained in traditional engineering programs with no exposure to formal patient and clinical knowledge (Reid et al., 2005; Ng, 2011). On the other hand, research shows that individuals in the health care profession find mathematical and analytical logic challenging to understand (Ng, 2011; Schell & Kuntz, 2013). Moreover healthcare professionals use many medical devices while they may not have the knowledge and understanding of mechanical and engineering concepts of those devices (Ng, 2011). This lack of shared knowledge may cause difficulties in their interaction and understanding their needs. As Ng states, "With this knowledge imbalance, jointly manipulating complex engineering principles to solve intricate medical problems is no easy task" (2011, p. 449).

- **Language**: Inter-related with knowledge, the language used by doctors and engineers, with occasionally unclear definitions and varying emphases can make the communication between doctors and engineers difficult. The technical terms and language of each discipline are not easy for the other profession to understand (Yoda, 2016; Cummins et al, 2018). Therefore, collaborators find difficulties in expressing themselves and describing the complicated subjects (Cummins et al., 2018). The differences in their language lead the collaborators to take different approaches and perspectives to the problems, which ultimately results in poor communication (Orchard, Curran, & Kabene, 2005).
- **Allocating time and resources**: Gale and his colleagues (2011) have identified other barriers such as physicians not allocating enough time or committing enough energy. Also, there are external limitations on what biomedical engineering researchers can accomplish based on financial resources, personnel availability, and scheduling which were highlighted. In his study, Yoda (2016) similarly finds that physicians are busy professions which results in their lack of time for enough involvement in collaboration. In times when engineers have clinical questions about the project, this lack of time and access to clinicians neither help the communication nor moving the project forward.
- **Different goals and intentions:** Matsuki and his colleagues (2009) state that engineers usually tend to think in technical terms with little appreciation of clinical medicine. Their concern in designing medical devices is mainly about improving the current technology at the expense of use. On the other hand, physicians may have difficulty with using the new medical devices. Unless clinicians previously experienced collaboration with a biomedical engineering team, it may be difficult for them to recognize its potential contribution (Gale, Stack, & Dargaville, 2011). As Yoda (2016) argues, doctors seek to improve the lives of

patients, while engineers focus on designing useful devices. The former use personal knowledge: the combination of practical experience with applicable knowledge. The latter operate in a rhetorical realm that emphasizes research and development. He added, “although there are overlaps of those disciplines there still remain the difficulties” (p. 202).

2.4.2 Suggested solutions

- **Education:** Difference in language and terminology, as mentioned earlier, is one of the common barriers to interprofessional communication and collaboration (O’Daniel & Rosenstein, 2008). Ng (2011) suggested teaching engineering to doctors, and teaching medicine to engineers as one of the ways of improving the interaction between doctors and engineers. Matsuki and his colleagues (2009) also recommended developing and delivering educational programs (two basic and advanced intensive courses) as an approach to bridge the knowledge gap between these two groups. Moreover, in order to overcome the existing knowledge gap and achieve a “knowledge common ground” (p.91) between physicians and engineers, Matsuki and his colleagues recommended educational programs such as REDEEM and ESTEEM. These courses are offered to engineers at Tohoku university in Japan as part of their education program for working engineers. They state that offering the basic learning course “Recurrent Education for the Development of Engineering Enhanced Medicine” (REDEEM) and “Education through Synergetic Training for Engineering Enhanced Medicine” (ESTEEM) as an advanced learning course has helped to alleviate (if not entirely remove) the communication gap. Moreover, the biomedical science lectures, which are mandatory components of this program, help working engineers learn medical terminology and knowledge (such as human anatomy, cellular and biology sciences). Having in mind the learned tendency of engineers to apply the theories and implement them into real-world issues, this program provides components like real clinical case studies or disease-based lectures for engineers. Through these components engineers attend panel discussions that include surgeons and (medical doctors) MDs who review different cases and discuss the relevant clinical issues within those cases. While engineers learn the ways of doctors' thinking and problem solving through the discussions between surgeons and MDs, engineers can freely ask their questions, learn the structure of those cases and disease, and apply engineering theories to the discussed clinical issues.

Other research shows that programs such as "Engineers in Scrubs" or (EiS) offered at the University of British Columbia improves the interaction between these two groups by providing opportunities for engineering students to visit hospitals and getting familiar with clinical environments (Hodgson, Tam, & Van der Loos, 2014). While completing the interdisciplinary projects, engineers learn how to unpack the clinical issues and needs by applying engineering concepts and technologies.

The focus on expanding the educational programs especially for biomedical engineering disciplines is growing (de Rujiter et al., 2015, Eberhardt et al., 2016). Most of these programs are applying the multidisciplinary team-based learning environment by bringing clinicians, engineers, and business together. Through these programs, students learn how to apply the experiences of different disciplines together with engineering principles into designing and developing effective medical devices while they have more confident in themselves as engineers (Eberhardt et al., 2016).

- **Taking each other's perspectives:** On a broader level, Reid and his colleagues (2005) show that there are significant cultural, organizational, and policy-related barriers between these two professions. Nevertheless, they argue that even with distinct vocabularies, epistemologies and analytical tools that these two professions employ, it is possible to overcome this gap by comparing similarities and differences in their roles, skills, problem-solving approaches and leadership. Through examining these similarities and differences, members of each profession can better understand the other's perspectives and ideas and improve their performance accordingly.

- **Counting small interactions:** Sometimes, to improve patient care, even small amount of collaboration and communication during the application of medical devices helps. For instance, in operation rooms (OR) surgeons can use a medical device more efficiently when they share any problems they encounter with engineers (Campbell & Sridharan, 2017). In one such situation, a new medical fiber optic imaging device—"a device to help determine tissue perfusion in the operation room" (Campbell & Sridharan, 2017, para. 4) was ready to be used. Although this innovative device had successfully passed all its engineering tests and clinical ex-vivo trials, it would switch off in the OR for no reason. Surgeons shared this problem with engineers and later, the engineering team was able to make small adjustments so the device worked in the OR. This successful collaboration between engineers and surgeons is one of many examples showing how a problem in the world of medical technology can be solved through the ability to effectively communicate even in discrete situations. Surgeons, as one of the main users and those who spend most of their time working with biomedical technologies in the OR, may sometimes face these kinds of issues during surgery. Campbell and Sridharan (2017) also noted that while surgeons can offer tremendous help in overcoming the challenges with medical devices and advancing forward the project, for many reasons such as "time restraints, lack of guidance, unfamiliarity with each other's specialty, etc." (para. 2), they may not be interested in getting involved in collaborative projects with engineers. It was recommended by the authors that surgeons not be discouraged quickly when facing a problem but to ask for help from people in other disciplines. Sometimes a simple email to a colleague could be a great starting point for productive teamwork (Campbell & Sridharan, 2017).

- **Increasing interdisciplinary interaction:** In another collaborative research project, Yoda (2016) studied the effect of communication between doctors and engineers on the productivity of the development of artificial retinas and cochlear implants. He found that development of a 'user-led' innovation "needs involvement of physicians as knowledgeable users of devices"(p.194), which was vital to their success. The importance of having doctors as users in research and development of medical devices has been emphasized in other studies (Shah & Robinson, 2006; Chatterji et al., 2008). While Yoda (2016) in his study recognized the value of physicians as users, he found that close interdisciplinary collaboration was needed for successful research and development of medical device projects.
- **Maintaining geographic proximity**: On account of the varied skill sets, team members also need to maintain proximity to one another: geographic, cognitive, organizational, social, and institutional. These five forms of proximity may substitute each other, if necessary (Boschma, 2005). For instance, if there is different disciplinary and knowledge base in collaboration between engineers and clinicians (cognitive proximity), or barriers of organizational, social, and institutional, these could be overcome with geographical proximity. Thus, close distance of researchers (geographical proximity) can create more frequent interactions between these two groups and make the collaboration more effective (Yoda, 2016).

- **Early engagement of clinicians and engineers:** Other studies have identified the early engagement of clinicians and engineers in the design and development phases as necessary for successful collaboration (DePasse et al., 2014; Bennet, 2014). For instance, at Mayo Clinic engineers and technologists collaborate closely with physicians and nurses from the very early stages of medical device design. Being part of the Clinic, engineers attend research meetings and surgical procedures, and engage in hallway discussions. This approach brings a multi-disciplinary team to projects including project managers, electrical, mechanical, biomedical, and chemical engineers for whom their different individual perspectives and skills improve the collective success of the project.
- **Respecting different knowledges:** To find out more about successful teamwork in such interdisciplinary collaboration, Gale and his colleagues (2011) investigated two case studies. The first one studied collaborative research in hospital-based neonatal care. This project involved research and technology to enhance the delivery of supplementary oxygen to premature babies (e.g. logging data from babies to evaluate the performance of current systems). The second case study comprised collaborative research in drug addiction rehabilitation involving clinicians from local communities. The aim of this latter project was to enhance the safety of take-home narcotic substitute medication (e.g. development of technology for the purpose of secure storage, remote assessment of patients, etc.). The project collaborators were clinical researchers, nursing staff, biomedical engineering research leaders, and engineering students. Although these two case studies were inherently difficult and very different from each other, the results showed that the groups were highly engaged; their points of view, knowledge and input played important roles in achieving their outcomes. Nevertheless this paper argued that respecting other disciplines'

knowledge and their priorities in such collaboration teams is what makes communication an effective one.

According to Gale and his colleagues (2011, p. 300), the following are some potential strategies for successful clinical research collaboration: 1) identifying active clinical researchers, 2) identifying sympathetic clinicians who understand Biomedical Engineering researchers and their work constraints, 3) focusing on problems that are identified by clinicians, 4) developing trust and understanding between biomedical engineers and clinicians throughout the research project and over an extended period of time, and 5) engaging high quality biomedical engineering postgraduate students and staff who are interested in working with clinicians and are familiar with the clinical environment.

In general, as mentioned earlier from other studies, maintaining successful collaboration especially when it comes to gather different collaborators from different disciplines need considerable efforts. Better communication and teamwork can be more secured once people who are truly interested in teamwork projects are gathered and their agreement on goals and defining roles and responsibilities of each member clarified (Huggett et al., 2011).

- **Regular communication:** Cummins and his colleagues (2018), surveyed 21 gastroenterologists and engineers about the benefits and challenges of interdisciplinary research. This survey was distributed among engineers and gastroenterologists who attended at a Workshop on Minimally Invasive Endoscopy in 2017 in Edinburgh, UK. They reported challenges such as uncertainty about commercializing and marketing the product, challenges with the lack of common goals, culture and different working styles, concern about the difficulty in securing funding, maintaining regular interaction and communicating effectively (p. 437). Communication was identified as the as number one challenge since different medical and engineering terminologies represent an impediment to effective interdisciplinary communication.

Current best collaboration practice between engineers and clinicians suggests pursuing a common project goal through regular, direct communication premised in a common base of defined terminology specific to the relevant disciplines. Regular bidirectional contact and communication at every step of the collaboration proves essential to increasing the sense of responsibility and commitment, producing a quality work product, and successful collaboration (Huggett et al., 2011; Cummins et al, 2018). Moreover, open dialogue and interaction are needed in order to achieve a common interpretation and mutual understanding which ultimately helpful in overcoming the language barrier (McKibbon et al., 2013; Yoda, 2016).

2.5 Summary and research questions

Interdisciplinary communication both in healthcare systems (O'Daniel & Rosenstein, 2008) and among physicians and engineers is ranked as the main feature of successful collaboration (Yoda, 2016; Cummins et al., 2018). Having effective communication within a team environment enables that collaboration to be fruitful in a way that also helps reduce medical errors and patient harm. When collaboratively performing a variety of tests and experiments together to determine the utility and functionality of a medical device, physicians and engineers must also remember to undertake a safety analysis. All of these elements must be precisely examined to increase patient safety (Bennet, 2014). A practical way to achieve this safety objective would be to remove communication errors between doctors and engineers prior to proceeding with any stage of experimentation.

Despite the growing body of research in this area, we still have little understanding of foundations of effective communication and collaboration between physicians and engineers. This study aims to further explore the communication between these two groups and find out what may arise in their communication. Moreover, it explores some recommendations or facilitators that may foster such challenges. Thus, the following are the main questions of this study:

1) What arises in communication practices between engineers and physicians in designing medical devices collaboratively?
2) How can we address communication challenges?

By investigating engineers' and physicians' experiences of interdisciplinary communication, this research sheds light on communication practices. In addition to confirming the presence of communication patterns consistent with other research findings, this study utilizes its data to identify new issues and to explore alternative ways to improve communication.

Chapter 3: Methodology

"Methodology asks 'How can we know what can be known?"~Mann & MacLeod, 2015

In this chapter, I describe the research methodology approach and techniques that I have incorporated into designing this study, the approach to data collection and data analysis. To accomplish these tasks, I use one of Halcolm's[1] *Inquiry Parables* by Patton (2002). In his book *"Qualitative Data and Evaluation Method"*, Patton tells the story of "The Fruit of Qualitative Data".

> *"The story is about a scholar who lived in a village and spent most of his time in reading. Once he decided to begin journey to find out what "fruit" means as he always encountered this word in his readings. He searched a lot and finally found which land he needed to go to learn about fruit. After a long journey, he arrived to a large apple orchard in springtime. He was surrounded with trees all in blossom. He tasted one of the blossom but he did not like its taste. He continued and sampled a couple of more blossoms from other trees. They were all unappetizing to him. He came back home and informed other villagers on what he experienced in his journey and wrote a report. He reported that fruit was a much overrated food. Patton concludes: "Being unable to recognize the differences between the spring blossom and the summer fruit, the scholar never realized that he had not experienced what he was looking for*" (p. 3).

To be able to recognize what researchers seek in their research, Patton emphasizes the need to understand "what qualitative data and findings look like" (p. 4). Researchers need to ask 'What' and 'Why' questions to get a 'feel' for their methodology and qualitative practices. Incorporating Patton's ideas, I started my research journey with the most critical question of "Why am I conducting a qualitative study rather than a quantitative one?" and continued with more fundamental questions, such as "What type of qualitative design should I use in my study?", "What is my data going to look like?", and "How am I going to analyze my data?" More specifically, "how might my results advance theoretical understanding of collaborative practice?".

[1] Pronounced "How Come?"

In the next sections, I attempt to address the above questions and describe my methodology in more details. I start with identifying the phenomenon of interest and tell the story that inspired me to begin this journey—the story that helps to get a sense of what the *fruit* of my research might look like.

3.1 Identifying the phenomenon of interest

In 2010, I graduated from the University of Birmingham and received my Master of Engineering in Electronic and Communication Engineering. It was one of the most exciting and stimulating periods of my life. I started working as an electronic engineer at a medical device company in the United Kingdom right after I graduated. My job involved pacemakers—a device for patients with irregular or slow heartbeats, which regulates the pace and sense of the heart by sending electric currents, and measuring the voltage. This served as an inspiring experience for me to observe firsthand the integration of engineering and medicine.

I was on the research and development team, also responsible for reviewing complaints and repairing devices as needed. At the time, there were several hospitals that frequently complained about device malfunctions, which resulted in the pacemakers being returned to the company. One day, a tragic experience happened while I was working in our lab. I noticed that a pacemaker was returned due to an incident that had occurred during a surgery. After I opened the battery case of the device, I realized the batteries had been incorrectly inserted. As soon as I inserted the batteries properly, the device worked. The device assessment showed that there was nothing wrong with the pacemaker itself other than the user's (physicians or nurse's) misuse—a careless act in working with the device and a simple error that seriously threatened a patient's life.

During my work experience, I noticed that while medical doctors and specialists had difficulties using the devices designed by engineers, the engineers also had challenges in explaining the problems to them. Reflecting on that, I realized that there is a gap that interferes with smooth, effective and concise communications between physicians and engineers. This made me think about the reasons for this gap, dysfunctions in such critical medical devices, and the communication between doctors and engineers. I asked myself this *big question*: *"How can the communication between these two groups be improved in order to increase the efficiency and reliability of medical devices?"*

I conducted a review of the literature and observed a scarcity of studies on this topic. This assured me that I needed to understand the phenomenon of communication from the perspectives of engineers and doctors who work together or have had these types of work experiences in their past. To address this need, I designed my research in a way that explores this question that has critical implications for patient safety. Besides incorporating the existing literature in developing the conceptual framework, there are other ways (such as experiential knowledge, exploratory or pilot studies and thought experiments) that have been advised to be considered for researchers to bring more depth into their studies (Bezuidenhout & Schalkwyk, 2015). Thus, following the advice of my supervisor and committee members, I conducted the pilot study, which I describe in the next section.

3.1.1 Pilot study

I performed a pilot study prior to beginning the main one. The pilot study examined the experiences of two surgery residents and three engineers in training who have collaborated on medical device design teams. Sources of data included interviews, lab observations, and interview notebooks. The interviews took place with UBC engineering students who had worked with clinicians, and clinician/residents who had worked with engineers. Each of the five interviews had a duration of approximately a half hour. Observations took place at the Centre for Hip Health and Mobility biomedical lab in Vancouver. During two 3-hour sessions, the engineers and a resident worked together on a collaborative project. Only engineers worked on the device at the first session, while in the second session the resident join the group. I wrote a vignette describing one of the scenes from the observation sessions (See appendix A). Notes from the observations were recorded in a field notebook. The settings of interviews, as well as my thoughts, assumptions, and ideas were all recorded in the notebook.

I later reviewed this notebook to perform coding and data analysis. Two main categories, each with two themes, appeared prominently. The two categories were differences and priorities. The two themes for differences were 'using different terminologies/languages' and 'having different ways of thinking.' The two themes for priorities were 'the problem of time pressure' and 'lack of having common goals'. By examining the patterns in this experiment, I felt I could better understand the current state of these issues in current professional practice. The pilot study proved helpful in several ways, such as allowing me to try out interview questions and revise them as needed. The pilot study also allowed me to improve my comprehension of how these themes and findings influence long-term collaborative enterprises. My Master's thesis endeavors to look at this collaboration by both expanding the number of participants from the pilot study and including current practicing professionals from the respective disciplines.

3.2 Research design

This study uses a qualitative research methodology to explore the communication phenomenon from the perspectives of engineers and physicians when they work collaboratively on developing medical technologies. Qualitative methods are best for studies that are aimed to reveal meanings, experiences and perspectives of participants' points of view (Sutton & Austin, 2015). The goal of qualitative research is to question, explore and identify phenomena by providing detailed descriptions of various data acquired through means such as observation, interview, journal writing and reflection (Hammarberg, Kirkman, & de Lacey, 2016).

While I use a qualitative approach, as opposed to a quantitative method, I acknowledge that each approach brings its own insights and different perspectives to research (Cleland, 2015) and by no means do I intend to assume that one method (i.e. qualitative) yields more important insights than the other (i.e. quantitative). Instead the nature of my research questions is best answered through a qualitative approach (Silverman, 2006) because my question focuses on the nature of engineers and physicians' understanding and interpretations of one another. This study thus involves human subjectivity and interpretation with a "focus on capturing the complexity of 'real world' phenomena" for purposes of gaining a deeper understanding of collaborative practice (Leedy & Ormrod, 2013, p.139).

3.2.1 Qualitative approach

Some commonly used qualitative approaches to inquiry, include narrative studies, grounded theory, ethnography, case study, and phenomenology (Creswell, 2007). Each approach has its own strengths and limitations. All approaches could potentially be suitable designs for my research, however I selected a 'case study' approach in order to answer my research question.

3.2.2 Case study

According to Creswell (2007), case study research is a qualitative approach that involves the investigation of one or more cases within a bounded system over time. The focus of case study is to develop an in-depth description and analysis of a case or cases while its unit of analysis is more than one individual (Creswell, 2007; Cristancho et al., 2018). A case study allows for "investigation of a phenomenon in real-life contexts" (Yin, 2009, p.18). The aim is at understanding a phenomenon and the context in which it occurs (Artino et al., 2015). Adopting the above definitions, this case study explores how engineers and physicians, as different disciplinary groups, develop an in-depth understanding of the communication practices around collaboration on medical device design and development.

In his book *"Case Study Research and Applications"*, Yin (2018) argues that a case study needs to be defined in a way that considers the experiences of both parties; both groups of engineers and physicians. The result of collecting evidence from only one organization to examine its relationships with others would produce biased conclusions. Accordingly, to avoid this flaw in designing my case study, I included perspectives from both engineers and physicians in order to understand both groups' experiences collaborating with each other. The participants and six cases of this study are described below.

3.2.2.1 Participants

Identifying participants began as an initial contact with the UBC Hatch program. Hatch is an "incubator for technology-based start-up companies" located at UBC-Vancouver campus[2] which included some start-ups with potential partnerships between physicians and engineers. I received a positive response from Hatch about outreach to potential doctors and engineers who may be interested in participating in my project. However, after receiving ethics approval, I realized finding enough numbers of engineers and clinicians (especially clinicians) based on their availability and interests was not possible and therefore limiting my connected to Hatch-related companies was not possible.

This led me to use another approach—snowball sampling—to find participants. Snowball or chain sampling is one of the purposeful samplings in qualitative studies (Patton, 2002). Snowball sampling invites the researcher to ask well-situated people "Who knows a lot about …?" and "Whom should I talk to?" (Patton, 2002, p. 237) Thus, I contacted my supervisor and committee members to put me in touch with engineers and surgeons who might be interested in participating in my study. I incorporated the same sampling strategy with each interviewee who I met with, asking them to introduce new doctors and engineers who might be interested in participating in this study.

Potential participants were invited to participate in interviews by the principal investigator and the co-investigators via email. Once potential participants allowed the researcher to communicate through email, an ethics-approved letter of information that outlined the study was provided to

[2] http://icics.ubc.ca/hatch/

each participant. Those participants who consented were contacted to arrange a time and location of the interview.

3.2.2.2 The six cases

This research project was completed with 6 cases. In all 6 cases there was one engineer and one doctor who had already worked together. There were 12 participants: 6 engineers (2 females and 4 males) and 6 physicians (3 females and 3 males), resulting in 12 interviews. All the participants were interviewed separately. Recruitment of participants in all cases was limited to those who had already worked together or are still collaborating. All the participants had been working with each other as pairs for at least five years. Out of 6 cases, three were located in Canada and three in the United States. Table 3.1 shows the description of each case.

	Education	Position	Location	Years of collaboration experiences
Case 1	Mechanical Engineer Orthopedic Surgeon	Faculty members	U.S.A	15 Years in total
Case 2	Computer&Electronic Engineer Orthopedic Surgeon	Faculty members	Canada	15 Years in total (This case as a pair has been working together for 11 years)
Case 3	Mechanical Engineer Orthopedic Surgeon	Faculty members	U.S.A	15 Years in total (This case as a pair has been working together for 5 years)
Case 4	Biomedical Engineer Orthopedic Surgeon	Faculty members	U.S.A	15 Years (This case as a pair has been working together for 5 years)
Case 5	Mechanical Engineer MD-Cardiologist	Industry (Retired Faculty)	Canada	5 Years
Case 6	Physicist Orthopedic Surgeon	Academic (Retired Faculty)	Canada	14 Years (This case as a pair has been working together for 9 years)

Table 3-1 Description of the six cases

3.3 Data collection

Collecting qualitative data is intended to produce information that helps the researcher to answer his/her "research questions, capture the phenomenon of interest, and account for context and the rich texture of the human experience" (Paradis et al., 2016, p. 263). To acquire such information, I collected interview and a kept a reflective notebook. The reflective notebook was used to write my thoughts, assumptions, and feelings prior to and after each interview. I also recorded the repeating topics and surprising comments that emerged in the interviews. The notebook was used later in analytic memoing and comparative analysis. To better understand the process of interviewing and the questions to ask in my interviews, I referred to Manen. Manen (1990) explains that a researcher adopts one method over another based on the questions he or she asks:

> *"A research method is only a way of investigating certain kinds of questions. The questions themselves and the way one understands the questions are the important starting points, not the method as much. But of course it is true as well that the way in which one articulates certain questions has something to do with the research method that one tends to identify with. So there exists a certain dialectic between questions and methods"* (p. 2).

Here, Manen focuses on the importance of the questions that a researcher asks as well as the way he/she understands them. It is like the researcher is moving dialectically between the questions (as part of the research) and the whole, and every time he/she makes such a move a new understanding emerges. The German philosopher, Gadamer (1960), makes similar points regarding questions. He argues that questioning is an essential aspect of the understanding process as it helps create new horizons and understandings. Gadamer states that the questioner must be open, considering different possibilities in order to expand horizons: "the range of vision that includes everything that can be seen from a particular vantage point" (1960, p. 307). In other words, questioning means to go beyond what is close by. As one moves, one's horizon changes too. This is what I tried to keep in mind when collecting my data—not to be limited by my own experiences and perspectives, but to push past those boundaries, and refine my questions to acquire new perspectives (an example is provided in the analysis section).

3.3.1 Interviews

Interviews were conducted with the 12 participants, each lasting between 30-45 minutes. The time and location of interviews were arranged by email. All interviews were audio recorded on a password-protected recorder. After transcribing each interview, the document was anonymized and assigned a participant code ID.

Initially, I conducted my first interview in a structured format. Structured interviews use a set of pre-determined questions (Paradis et al., 2016). The interviewer does not have the freedom to change the questions and their order. During one of the pilot interviews using the structured approach, I noticed that the participant was inclined to explain some details that were not directly related to my question—though that information might be considered useful. Given this, I did not continue with his detailed answer, as I needed to move to my next (already prepared) question. Recognizing the limitations of structured questioning, I decided to adopt a semi-structured method for my next interviews during the pilot and the main project.

While structured interviews can make the process easy and efficient, and bring consistency within data collection (since the questions are the same for all the interviewees), they can limit the flexibility for the interviewee to speak beyond the proposed question or enable the researcher to refine interview questions based on emerging insights. In semi-structured interviews, while the interviewer prepares a list of pre-determined questions, he/she is free to ask different, unlisted questions based on the thoughts the interviewee shares (Robson, 2002). Similarly, the interviewee has the opportunity to open up his/her ideas and explore different aspects of the question. I also noticed that the interviewees preferred a natural flow of conversation as it appeared to engage them with the questions. This can bring more depth to the conversation and the ideas presented during the interview (Cristancho et al., 2018). For example, if the participants shared a barrier or benefit in their communication experiences, I asked them to explain that benefit or barrier through an example (if they had one in mind). To keep the conversation flowing, other questions like "why is that difficult/beneficial?" or "what else would you like to add" were asked. The participants were mainly asked about their collaboration experiences, as well as the benefits and barriers of their communication with each other and the role they perceived themselves to play in the interpersonal dynamic. To bring consistency into my semi-structured interviews, I designed key questions (Robson, 2002) with a focus on "the benefits and challenges of their communication". (See Appendix B)

3.3.2 Interview notebook

An interview notebook was used to record my thoughts, the setting and type of each interview, as well as the keywords and main topics covered throughout the interview (an example is provided in table 3.2). The notebook was more like a journal with a focus on my assumptions, thoughts and feelings prior to and after each interview. This data source provided an opportunity to reflect and make notes of my thoughts after each interview. For example, after each interview when my experience was still fresh, I asked myself the following recommended questions by Patton (2002) and made notes answering questions such as: "Did you find out what you really wanted to find out in the interview? If not, what was the problem? Poorly worded questions or wrong topics?" (p.

384). To find out what I was exploring in this study, I tried to focus on my research questions when interviewing participants. At the same time, I kept myself open to the ideas brought up by the interviewees—even those that were not aligned with my research questions. The reflection and questions were shared with my supervisor and committee members and implemented any changes in time for the next interview. The table (3.2) illustrates one of the notes from my interview notebook.

PARTICIPANT #3

DURATION OF INTERVIEW	55:10
TYPE OF INETRVIEW	Semi-structured
SETTING OF INTERVIEW	Phone interview
WHO WAS PRESENT?	Interviewer and Interviewee
MAIN TOPICS COVERED IN THE INTERVIEW	Characteristic of engineers and doctors, how communication changed over time, funding
KEYWORDS	Communication, collaboration, more experience and its effect on communication
NOTES BEFORE/AFTER INTERVIEW	After doing my first two interviews and reviewing my notes, I noticed that I was worried about time. I wanted to ask all the interview questions from the interviewees. This made me to make some assumptions, during the interview, about what they shared instead of asking them for more explanations. ▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪▪ The interview just finished. During the interview, I tried to detach myself from the questions and listened more in what interviewee was talking—following my supervisor's advice. In this interview, I asked my next questions based on the interviewee's answer and respond to the previous question. I found this interview more engaging. For example when he talked about having confidence that could affect communication, and I asked him for an example that having confidence make his communication with surgeon smoother. The example of paper's authorship was mentioned and this example open another conversation about trust and expectations roles in communication.

Table 3-2 Illustration of an interview notebook

3.4 Ethical consideration

Behavioral research ethical approval was granted to the principal investigator, Dr. Sandra Jarvis-Selinger, on August 30, 2018 under the certificate number of H18-01165 prior to beginning the research and collection of data. The interviews, as the main sources of data collection in this study, were completed with only volunteer participants. I kept hard copies of transcripts in a locked cabinet, protecting participants' confidentiality and anonymity. All transcripts were anonymized using a code ID and those code IDs were used in my thesis.

3.5 Data analysis

The main goal of my data analysis is to create themes that represent the communication experiences of the participants as a result of their collaboration. This was an exploratory study where thematic analysis was used to identify, analyze and report repeated patterns of meaning, i.e. themes that were identified across the data set (Braun & Clarke, 2006). Each interview I conducted helped to document the communication experiences of engineers and doctors with each other during the course of their collaboration. The result of documenting the participants' views and experiences generated themes following the research questions in this study (Paradis et al., 2016). During analysis I was primarily interested in answering my research question about participants' communication experiences, as well as the benefits and challenges of their communication with each other and the role they perceived themselves to play in the interpersonal dynamic.

Throughout the interview, some preliminary analysis was done concurrently with collecting data. For example, after completing the first few interviews, it became apparent that participants consistently mentioned that 'developing a relationships' affected their communication. This observation was noted in the interview notebook as something to be considered in subsequent interviews for further investigation. Thus, from that point forward, when participants mentioned that relationship affects communication, I followed with: “I notice you seem to be talking about developing a relationship with the engineer/physician; can you tell me a little more about that?” In addition to this concurrent analysis, the rest of the analysis was done as a separate, explicit step to interpret the data as a whole using specific analytic strategies and software.

Throughout the final stages of analysis I completed the coding through the combination of: a) traditional method (readings, taking notes, and sorting and organizing the coding through colored sticky notes) and b) a computerized one through the utilization of the qualitative software program, Nvivo (Maher et al., 2018).

In the first phase of my analysis, I printed the transcripts and read and re-read them keeping in mind theory-generated coding (Marshall & Rossman, 2015). I looked at the portions of information that struck me as potentially important or relevant to my research inquiry, and took note of them in my journal (Merriam, 1998). The readings and notetaking helped me create preliminary codes in my mind. To visualize codes and find the relationships between codes, I began open coding using colored papers (See Appendix C). I did this initial coding based on concepts derived from the literature review and pilot study (for example, the priorities and differences of engineers and physicians, challenges of communication, etc.).

In the second phase of my analysis, I imported all the transcripts into Nvivo. It is important to stress that this computer software program does not analyze the data, nor interpret any coherent meaning. Its main purpose is to assist the researcher in organizing and sorting the codes (Yin, 2018; Maher et al., 2018). Since the focus of my study is on physicians and engineers who have already worked together, I took the 12 participants as 6 pairs of clinicians and engineers (with the experience of working together) and looked into and coded each pair separately. Applying Yin's (2018) suggestion, I then tried to "play" with my data and recorded my thoughts about each case as memos or notes to myself. During this second stage of analysis, I was looking for "patterns, insights, or concepts that seem promising" (Yin, 2018, p.167). Writing memos and notes to myself was a helpful practice in moving from data to more conceptual level of developing meaning through coding, and finding relationships between codes and categories (Miles & Huberman, 1984). Organizing these codes helped me then identify patterns in the dyadic pairs, such as: 'the effect of sharing workload on communication', 'the importance of being dedicated and interested', etc. Streamlining the evidence review helped validate these patterns (LeCompte, 2000).

Finally, I started to compare and contrast salient patterns from all 6 cases. The result of exploring the similarities, differences, and any repetition of codes and patterns led to create a single 'cross case' set of codes (See Appendix D). By comparing the data characterizing the codes, I could verify the codes and find three main categories. For example, I noticed that being a good listener was highlighted by some participants. The participants recognized that attentive listening affects the communication and helps members be more engaged in discussions during meetings. In addition, the codes implied that other qualities such as 'showing interest and dedication' and 'being honest and open-minded' influence the communication as well. Therefore, a main category emerged as 'team member qualities' with three sub-themes: 'having interest and dedication, 'being honest and open-minded', and 'listening attentively'. At the high level, the three main emerged categories were: 1) Building relationships, 2) Team member qualities, and 3) Communication techniques. By moving back and forth between the transcribed data and the codes, I could monitor the reliability of my interpretations and proceed to the descriptive stage of summarizing my findings (Miles & Huberman, 1984). Moreover, I had several peer debriefing with my committee members while analyzing my data and took detailed notes in order to enhance analytic rigor (Anney, 2014).

3.6 Reflexivity

Reflexivity is the self-examination of how one's personal background and experiences may bias a project (Finlay, 2002). It involves an active recognition that consciously or subconsciously, researchers cannot completely remove themselves from the assumptions they have acquired through their professional and life experiences (Finlay, 2002). Rather than eliminating such bias many researchers choose to intellectually embrace bias as an opportunity for insight (Frank, 1997). This is of particular importance in a qualitative study, such as my project, in which true objective neutrality would be hard or even futile. Recognition of this reality does not lessen the value of a qualitative study, in fact, it enhances it (Finlay, 2002). By reflecting and openly disclosing the risks of bias, and revealing the sources of those potential risks, the researcher's credibility rises both internally and externally. It rises internally because it encourages the researcher to mitigate the acknowledged potential bias. And it rises externally because of the researcher's transparent intellectual honesty.

I am an engineer whose experiences revolved around developing medical devices in a work environment predominantly without the presence of medical professionals. I did not personally interact closely with physicians during my work as an engineer. The consideration of my own relationship to the subject of my research is a critical function of reflexivity (Cristancho et al., 2018). While, on the one hand, my lack of collaborative experience as an engineer with physicians suggests that I do not have any personal assumptions about how clinicians communicate, it also means that my pre-project baseline of knowledge is based mainly on what I read or what my engineering colleagues shared with me about their experiences. Furthermore, as an engineer myself, I might be more inclined to look at the communication between physicians and engineers from the perspective of an engineer. Being conscious about my personal assumptions and acknowledging any bias can help mitigate them and enhance my analytic rigour.

In my interviews, some of my structured format questions might be more critical, or less critical, of the medical cohort—just because of the fact that I know less about them due to my lack of experience in medical settings. By knowing that I might have this tendency, and by exposing it, I worked diligently to ensure that my questions and pattern interpretations did not make judgmental assumptions about one side or the other. For instance, I actively tried to mitigate the risk of bias by moving toward a semi-structured format that enabled interviewees to cover the topics that were most insightful to them. By making my questions flexible, each interview was more about the interviewee than about the interviewer. This provides some measure of increased control against bias of the researcher. Guillemin and Gillam (2004) refer to this as a reflective practice to improve the quality and validity of research.

Chapter 4: Results

In this chapter, I report the findings of communication experiences of twelve participating doctors and engineers who have worked collaboratively over time (Table 4-1). The findings also address the communication difficulties the participants experienced through their collaborative work. There are three main themes that emerged from the data analysis: building relationship, team member qualities, and communication techniques. These themes and their sub-themes will be summarized in this chapter, along with sample quotations (verbatim). My dataset includes six cases, each of which is composed of a single physician and a single engineer. In the following quotations, speakers will be identified by an abbreviation indicating their case number followed by their profession. So C1E means that the case one engineer is the speaker, and C1D means the speaker is the case one doctor.

The case of this study, as mentioned in methodology chapter, is defined based on the communication experiences—that is, the case includes those physicians and engineers who have already worked together. The participants were all professionals working with their partners for over 5 years. There was very little striking deviation between the pairs, however as noted in Table 4.1, some features are highlighted in some cases more than others. In Table 4.1, 'D' stands for medical doctor and 'E' stands for engineer. Under each sub-theme, E indicates that only engineer talked about that sub-theme, D indicates only the doctor and DE indicates both doctor and engineer talked about the related sub-theme.

Communication													
	Building Relationship					Team Member Qualities			Communication Techniques				
	Sharing workload	Developing Trust	Clarifying expectations	Needing time	Maintaining respect	Having interest and dedication	Being honest & open-minded	Listening attentively	Holding F2F/regular meetings	Giving continual Feedback	Drawings/Prototyping/Going to O.R.	Blocking surgeons' time in advance	Embracing differences
Case 1	**DE**	**DE**	**D**	**DE**	**D**	**D**	**DE**	**D**	**DE**		**E**	**D**	**D**
Case 2	**E**	**DE**	**DE**		**E**	**E**	**DE**		**E**	**DE**			**DE**
Case 3	**E**	**E**	**DE**	**E**		**DE**		**D**	**D**	**D**	**DE**	**D**	
Case 4	**E**		**DE**	**DE**		**DE**			**DE**	**E**		**E**	**E**
Case 5		**E**		**E**	**DE**	**D**	**DE**		**DE**	**DE**	**DE**		**D**
Case 6	**E**	**DE**	**E**	**E**	**D**	**DE**	**D**	**E**	**E**	**D**	**DE**		

Table 4-1: Emerged themes and sub-themes in studied cases: Contributing factors to effective communication

4.1 Building relationship

All six cases expressed the importance of building relationships to achieve effective communication: *"Once the relationship is established communications are pretty good"* (C2E). Based on participants' experiences, there are different elements which contribute to developing a better relationship between team members and ultimately better communication. Sub-themes that emerged from this theme as important factors in building a successful collaborative relationship include: sharing the workload, developing trust, clarifying expectations, needing time, and being respectful. Each factor is explained below.

4.1.1 Sharing workload

Sharing the workload was recognized in most cases, especially by engineer participants, as an important factor for building and supporting relationships. One of the doctors explained that a relationship will not last if the workload is not equal: *"I think some of the relationships I see that don't work well are the ones where only one person is doing all the work and that's not going to work. That's not going to last"* (C1D). Dividing work and responsibilities on a team based on the roles and expertise of the respective members helps develop stronger relationships, as one engineer outlined: *"… if there's a clinical question that comes up, I'll just defer to the surgeon. If there is an engineering question that comes up, they'll often defer to me. This delineation between sort of responsibilities and scope on the project makes relationships stronger. That generally makes communication work pretty well*" (C1E).

Another engineer highlighted the importance of sharing the work and responsibilities among members. This could assist with the progression of project phases and bring more satisfaction: *"…good collaboration consists of everywhere and everyone pulling a fair share of work… pulling equal weight is probably one of the biggest things you are going to like in terms of project lifespan"* (C3E). Moreover, strong teamwork requires that members and their ideas are treated equally, as one of the doctors illustrated: "*I think being equal partners and really understanding that what you both bring to the table is valued are very important aspects of good collaboration"* (C1D). When members of a team know that their ideas are valued by other team members, they are more willing to share their perspectives and to collaborate. In other words, as one participant pointed out, cultivating insights from both engineers and doctors is the most productive element of collaboration:

> *"You know it's typical that neither an engineer nor a doctor will think of the entire piece. There are elements of the device that have been contributed to by one group or another group or a combination brainstorming together. That's really the most productive thing in your communication is to have everybody sitting around the table and fiddling on a whiteboard…"* (C5D).

Part of effective collaboration involves equitable distribution of roles within a work group. For example, in writing a grant and securing funding for projects, surgeons are usually assigned as the principal investigator (PI). When surgeons are involved not just as PI.s but also in the writing of grants, this expanded participation yields more clinically translatable research.

> "*My impression is engineers work more in isolation because it was hard to get someone else involved for the clinical input. But now that we have this whole kind of translational research concept and that it has to be translatable to the real world I think now the shift has been that they now really truly understand that you especially if you want to get funding you need to show now in your grants that this is clinically translatable [and] it does make sense. I think that they see that those grants that have clinicians involved potentially are going to be more impactful because it's going to be more clinically relevant"* (C1D).

While having a surgeon as principal investigator in the project significantly affects the research, this should not change the importance of dividing the responsibilities and workload among team members. Some of the engineers in this study mentioned the need for physicians to improve collaborative engagement, and participate in roles beyond that of principal investigator.

> *"I had a collaboration with a general surgeon [who] was a principal investigator of the project …We would meet with him probably once a month and then eventually it just became impossible to get a hold of him or get a reply from him for a lot of things. So there were some technologies that we were developed and he was happy to test them but we had to sort of work around his schedule and basically beg him for the actual interaction to take place. And of course he expected to be an author in all the papers and he didn't really contribute to the write up itself. Everything was like "oh yes it looks fine" if we got a response from him. So eventually that relationship deteriorated to the point that the projects didn't continue"* (C2E).

4.1.2 Developing trust

Trust contributes to establishing deeper levels of exploration and collaboration. Trust is an "*ongoing process*", as one of the engineers mentioned (C6E). It evolves over time and involves consistency. Once trust is established, the relationship grows. For instance, one of the doctors explained that in a collaboration in which "*engineers and clinicians bring different knowledge and* *expertise to the table"* (C3D), having trust in each other's knowledge and skills leads to recognizing and valuing the other person's opinions:

> *"I think my relationships have been very trusting and I value that. I think you do have to have faith that their skill and their knowledge about the engineering side of things is valid and there has to be a lot of trust. He [the engineer] has to trust me that my clinical opinion actually makes sense and I trust him that whatever he says does work from an engineering side of things. So you have to trust one another a lot because I don't know enough about the nuances of his discipline"* (C1D).

In addition, some of the engineers suggested engaging in collaborative activities outside the main reason for teams to exist together (e.g., medical device development) seems to help build trust. For example, working on publications together can also help grow trust in this field, as one of the engineers stated: *"…when you do publish together or do things like that [they] really irons out a lot of little winkles that you almost experience with any personal or professional relationship….it helps growing people's trust over the years which has been very important "* (C3E).

4.1.3 Clarifying expectations

Being clear about expectations, especially early on in the relationship, and having frank and honest conversations about them with team members is essential in building relationships. As one engineer outlined:

> *"I think, in the medical doctor and engineer relationship, they have to have some management of their expectations early on….one thing I've realized over time being in medical projects is that managing the expectations of people or understanding usually where the red flag areas are in terms of the expectations of how the project's going to go is one of the things that you have to identify and you have to have a frank conversation about early with"* (C6E).

Setting clear expectations also helps when team members write together. Without clear expectations in place up front, there will be confusion and sometimes frustration down the road. If everybody knows what is expected from them, they will be more invested and engaged, and ultimately more successful in their writing.

> *"I think one of the keys though is that you do need to set expectations right up to the front end like who is going to be the primary author, who is going to be senior author, what are the expectations from you or from them. I think it does have to set those expectations right up front. There's no confusion when the final product is done"* (C1D).

Furthermore, clarifying the expectation and reaching agreement particularly around their responsibilities in the project was highly emphasized: *"If we're going to do [this project together] then I'm going to do my bit and I need you [doctor or clinician] to do your bit. So this [sharing the responsibilities] is probably an expectation management that I would be very early in a conversation"* (C6E).

In addition to setting common, fundamental expectations, the failure to focus on the real clinical needs of a project was also identified as a significant challenge by participants, especially by clinicians.

> *"Not knowing the language can make misunderstanding but misunderstanding is usually something that we can resolve. We can work through like specific terminology. The bigger problem I have is with us not asking the right clinically relevant questions and directing needs towards something that's actually going to change clinical practice as opposed to just being the next step in a multi-year project, that's about more of, that ultimately related to terminology and languages but it's more understanding and losing a focus of what's actually clinical relevant"* (C4D).

The engineer participants also recognized the value on centering the clinical needs when designing a study. The real clinical needs lie where the doctors interests are and they get more motivated to collaborate on those projects. Doctors' interest is mainly where they see the direct benefits of that project for the patients. In other words, doctors find it difficult to participate in projects that do not ask relevant clinical questions. The engineer of case two pointed this out: *"If they [doctor] see* *that there is a direct benefit for their patients then they would be more interested in supporting that work"* (C2E). In another case, the surgeon elaborated:

> *"So there's a disconnect between the problems that we see clinically and the questions that are currently being asked in engineering labs and there is not a whole lot of communication in terms of […] 'What are the biggest problems that you see from an engineering standpoint and what are the biggest problems that you see from a clinical standpoint?' and the fact that those two don't line up in general"* (C4D).

Thus setting clear expectation, incorporating the real clinical needs and inputs to the project could eliminate the communication difficulties, as one of the surgeons mentioned: *"We really haven't had great communication difficulties because they've been very open minded and they are really trying to understand what are the needs in surgery and how they can address certain gaps and or deficits"* (C2D).

4.1.4 Needing time

'Building relationships takes time'—this was commonly experienced by both of engineers and clinicians of this study. One of the engineers mentioned, *"…a relationship doesn't happen right away. It really needs time to develop and evolve at all time"* (C4E). To build a meaningful and collaborative relationship, team members need to communicate their expectations over time; they need to learn not only from each other but also about each other's world and disciplines. This helps collaboration; more specifically, it directs the members to ask the relevant clinical questions:

> *"I don't know that necessarily the background would make a difference but by actually being in each other's worlds for a period of time will help you direct your questions appropriately... Asking right clinical questions happen just by spending time together in each other's world that is how the collaboration is going to work better …I don't think that there's anything necessarily worked best as other than sort of being immersed in an engineering or medicine environment"* (C4D).

Moreover, working with doctors and engineers with different lifestyles can affect the nature of communication. For example, the busy schedules of physicians, as well as the volume and sensitivity of their work in regards to saving people's lives, may leave them little time to follow up on interactions with the engineers, such as replying to their emails or returning their phone calls. This, however, can be different for the engineers due to the non-urgent nature of their work. As one engineer described:

> *"It takes a lot of patience in that every clinician that I've really interacted with...It's not that they're slow to learn things. They don't have a whole lot of time and so my interaction expectations with surgeons is, for example, to write an email and expect a response within a week hopefully, whereas with engineers I typically email someone and expect a response within 24 hours. And this is just a lifestyle. I think more than anything it's not meant to be a knock on the surgeon. They literally have like pressing needs that are with regard to people's welfare and other people's health and safety whereas our lives are a little bit different"*(C3E).

It is also necessary that both groups understand each other and give multiple chances to one another in order to maintain the relationship. Giving multiple chances to your team members, not only help your relationship but also facilitates an environment where some members may perform favors for each other, when needed. As illustrated by one engineer:

> *"I think just sort of being sensitive to the other group and not burning bridges help your communication. So if somebody irritates you give them another chance and a third chance and a fourth chance because that's kind of what relationships are… Eventually, you can start doing favors for each other which help you both out and make things go smoother and better"* (C1E).

4.1.5 Maintaining respect

Creating an environment in a team where members respectfully exchange different thoughts and opinions helps build stronger relationships. As mentioned by one of the engineers: "*I think being not getting offended with things, being understanding where people are coming from and being respectful to different perspectives and ideas really effect your relationship"* (C2E). Respect is also imperative when a team member is challenged with another member's idea or question. Maintaining respect while trying to understand the question and the other team member's perspective enhances relationships. One doctor explained:

> *"this sounds like motherhood, but it's important especially in developing your work relationship, treat your colleagues with respect and if they have a question it's because they either don't know the answer or they're challenging your solution which is OK because maybe it needs to be challenged"* (C5D).

4.1.6 Building relationships: conclusion

There are several factors that contribute toward building relationships effectively: a shared workload, developing trust, clarity of expectations, a commitment to mutual respect, and allocating sufficient time to develop these aforementioned components. One of the fundamental pieces in team communication is holding a frank conversation about everyone's expectations and reaching agreement on roles and expectations, particularly around workload and responsibilities. Participants, especially engineers, highlighted the importance of dividing the responsibilities and having an equitable distribution of roles. When too many tasks fall on only one or two members of a work team, the burden on the primary contributors can be overwhelming. Moreover, taking diverse responsibilities as opposed to constraining themselves to the typical assignment of roles can lead to greater understanding and help their communication.

Greater understanding of each other, along with valuing each other's knowledge fosters respect and developing trust among team members. It's important to focus on clinical aspects according to both physicians and engineers. Despite this, there remains a gap according to physicians in the research studies between research questions and real clinical issues. This is why the participants, both engineers and physicians, need to spend more time in each other's disciplines and become familiar with the real needs in each discipline. In addition, participants experienced that relationships were constantly evolving, and so there was a need for allocating sufficient time to develop their communication.

4.2 Team member qualities

It is not a secret that different people possess varied personalities, and that as such, "*there's a lot of different ways to handle different people"* (C1E). The participants of this project were all professionals with many years of experience in their work, and they confirmed that having experience equipped them with confidence. Participants, mostly engineers, suggested having confidence affects their communication, especially in sharing and exchanging their ideas and perspectives with their partners. In other words, having little experience or lack of confidence discourages members to share ideas openly, and this ultimately may lead to an ineffective communication.

> *"Being kind of a little bit more of a senior person than I obviously was when I started out I get more confident in my abilities and sort of what I brought to the table that was unique and helpful to the project…I probably got better at being more straightforward with what I thought about the idea and the project and that really helps communication versus me sort of just starting my head and trying to do whatever the surgeon was suggesting"* (C1E).

In addition to confidence, participants emphasized the importance of instilling certain other qualities in team members to support effective communication. These specific qualities which were most common among six cases included: Having interest and dedication, being honest and open-minded, and listening attentively. These sub-themes are described in the following section.

4.2.1 Having interest and dedication

Interest and dedication were recognized as keys to the success of promoting effective communication in all six cases: *"…Being interested and dedicated are probably the first things in having good communication…"*, one engineer mentioned (C2E). Working with members who are truly interested in the project turns the partnership into a very positive and collaborative experience. One doctor explained how *"… experience in working with engineers has always been completely positive. If the engineers are interested in it and have the time and resources and the doctors are interested and have time and resources, I think it will always work"* (C6D).

More importantly, interest and passion kept team members moving forward against time constraints, as outlined by an engineer: *"I had a very good communication with one of our surgeon [team members]….This cardiac surgeon could come at a meeting at 7:00 in the morning after having been doing the transplant surgery all night and he'd be falling asleep in the meeting but he was still there….it was the interest and dedication"* (C2E). In addition to these values, another engineer spoke about dedication and interest overcoming financial incentives and ultimately helping communication:

> *"In orthopedics department, we are constantly working with surgeons and their time incentives to actually do research, it is just pretty limited, and they basically don't have financial incentive to do research. It doesn't pay nearly as well as doing surgical cases. So you really need somebody that is engaged and very interested and wanting to do the research"* (C4E).

4.2.2 Being honest and open-minded

Participants recognized honesty and openness as one of the essential qualities of team members. *"I'm just honest. I tell them what I think and they tell me what they think. As long as everybody is honest and open minded, I don't think there is a problem"*(C6D). Moreover, members needed to be open-minded enough to accept the challenges of interdisciplinary communication and the questions that arise from it. This involves readiness to receive new information and questions even if they undermine one's own position. One can always defend the challenged position while being open to new ideas. As one of the doctors illustrated: "*I think it's important not to be arrogant, not to believe that you know everything. You need to be always open to being asked to defend what* *you're saying and don't be obnoxious about being challenged on your opinion*" (C5D). In such collaboration, there are usually "*…lots of open discussions*" (C1D) with their positive and negative comments. The key is to be open to all sorts of ideas so that everyone feels they are heard and understood, and not dismissed or excluded. Therefore, as explained by an engineer: "*….you can't be too close-minded. You have to be open minded to what other people are proposing and accept that there will be good things and comment as well as the bad or negative [comments] and sort of participate in the overall process"* (C2E).

4.2.3 Listening attentively

Listening is key when exchanging ideas. In collaborative works, team members not only communicate by speaking to each other and exchanging ideas, but also by really listening to what each has to say. They listen with the intent to truly understand each other. This means they listen openly to different ideas and perspectives, value each other's input, and try to understand sometimes the most conflicting ideas. Such attentive listening involves accepting others for who they are while listening to them and coming to understand the differences in perspectives and ways of thinking. As one of the doctors stated, team members need to:

> *"…really keep an open mind like not being so channeled into your aims and goals because you really want to hear someone has a conflicting opinion… if you don't that's probably going to bite you later. So you want to really listen to what they're saying and value that input and really consider it because it will make the project stronger and because you're the clinician doesn't mean that you know everything. You may be too focused on one area and be totally going off on the wrong side of things"* (C1D).

Thus, in attentive listening, one shifts attention from oneself and what he/she has to say to instead focus on hearing and understanding what the other has to offer. The goal is not to give a simple answer. In other words, listening is not a means to an end, but as an end in itself—to listen in order to understand. It is this kind of listening that counts in communication. As another surgeon stated, in effective communication "*all parties listen*". His definition of listening also goes beyond the act of listening as a means to give a simple response. Instead, he suggests it is when team members *"… have focused attention and they are processing the information that's being provided to give 'thoughtful' responses back"* (C3D).

4.2.4 Team member qualities: conclusion

Interest, honesty, openness, and listening attentively are identified as important qualities that affect communication. Among these factors, dedication is recognized by both doctors and engineers as a fundamental piece as it ensures diligence, encourages timeliness, and facilitates focus. Honesty, both in terms of personal virtue and scientific integrity, provides an added measure of security and accuracy of the end results. Openness to new ideas and approaches allows innovation to flourish among team members. Active listening is a skill that helps members get more engaged in their conversations as well as gaining mutual understanding. Over years of collaboration, the engineer participants build self-assurance and confidence through their experiences which help them in their communication with doctors. The confidence of knowing one's own capabilities to perform a given task helps ensure a sense of collective trust among team members that the work can be completed with incisive thoroughness. Combined, these characteristics bring an environment of positivity that yields clear and effective communication.

4.3 Communication techniques

Engineers and doctors in this study, over years of collaboration experiences, incorporated the aforementioned techniques to maximize the productivity of their teams. By utilizing these techniques, the engineers and doctors achieved common goals by reducing barriers to effective communication. These communication techniques are: holding face to face regular meetings, giving continual feedback, drawings/prototyping/going to operating rooms (ORs), blocking surgeons' times in advance, and embracing differences.

4.3.1 Holding face to face regular meetings

The necessity of supporting regular, ongoing connections was important in all 6 cases. *"Doctors are busy and that could be a problem. So you need regular communication"*, an engineer said (C6E). It logically follows that misunderstandings and errors become likelier in an atmosphere devoid of frequent in-person contact. Maintaining physical proximity enables doctors and engineers alike to minimize distractions and notice subtleties that otherwise could be lost over the telephone or e-mail. One doctor explained, *"...sometimes you're not as clear as you should be in your suggestions or directions and they misinterpret some of your communications and go down the wrong path. But hopefully you find that out before too long and that's the importance of having regular and frequent interactions and meetings with follow ups"* (C5D).

While there are many different communication techniques such as *"…emails, video conference, or phone calls"* (C5D), face to face meetings were highly recommended. One of the engineers stated that having in-person regular meetings not only *"... gives you the best kind of opportunity to get as much as information as you need"*(C5E), but also help team members know each other and become familiar with each other's expectations: "*So more regular and frequent meetings help you learn more from each other. You also learn how they communicate and what their expectations are. This is an important component of communication"* (C4E).

Doctors are usually busy professionals and this may affect their involvement in collaborative projects. When doctors get a chance to attend the meetings, engineers have many questions about the project that they need to ask doctors. Considering their time limitation, engineers may ask too many questions of doctors when they come together. This may result in doctors feeling overwhelmed, and ultimately impact their communication. One engineer provided a particular example of the importance of regularly communicating to reduce such difficulties: *"[the] surgeon just wasn't available and when we finally got her into the room we needed so many things from her that she felt attacked… Constant communication could definitely help that"* (C2E).

While it is important to hold regular meetings, building trust and gaining respect can also ease the challenge of asking questions. As one of the participants suggested: *"I kind of had to learn to get gain their respect and kind of build that relationship so I could be a little more free in asking them questions because we asked them too many questions then they feel like you're being asking too many questions"* (C5E).

4.3.2 Giving continual feedback

Continual feedback was another technique that participants suggested to support effective communication. In collaborative research, receiving continual feedback and maintaining involvement from both partners, along with learning from each other and reaching mutual decisions, constitute some of the critical elements of building successful teams. These elements create lots of back and forth during the course of communication, necessitating greater time commitment. Effective communication must be open and bidirectional with regular intervals of contact. As one engineer mentioned, *"good communication opens communication pathways and regular communication is the most important component"* (C4E).

Regular contact enables team members to offer their specialized expertise in a way that invites constructive feedback for further refinement. As one of the doctor highlighted: *"they [engineers] all develop something and I'll ask them why. Or I'll tell them we need this and they all ask me out [medical questions] with the dimensions of the pelvis or with the bone stuff or stuff like that. So you know it's a back and forth thing. So you always need both expertise and feedback"* (C6D). This ongoing dialogue is a learning opportunity for both sides and yields insight into the varied approaches of team members for problem solving and their ways of analyzing specific challenges.

> *"It cannot be a type of meeting where the clinicians say that they would be great if you designed this new device and we'll see you in six months and go do it. You need to develop and evolve a relationship over time and then it's continual feedback from both sides. And then both sides learn how the other side approaches the problem and what are important considerations from inside*" (C4E).

Ultimately, continues feedback improves the quality of the collaboration by exchanging ideas and proposals for how to implement designs in a way that optimizes use, within the framework of improving patient care. This is explained by one of the participating engineers:

> *"I think it's a lot of going back and forth until we come up with an agreement. I don't impose things on [doctors]. It's going to be beneficial to doctors and it's going to be beneficial to the patient that they're the ones that know what that would be. So I propose solutions and they tell me whether they would work or not. So being able to do that back and forth of proposing things and then coming back to us with feedback and closing the loop basically is what makes the communication better and ultimately collaboration successful, it can't be one way"* (C2E).

4.3.3 Drawings/prototyping/ going to the operating room

There were many instances when participants discussed engineers have missing details while doctors tried to explain a concept to them. In these situations, the doctors either thought that the explanation was so obvious and therefore didn't need to elaborate on it, or they took for granted their experience in doing something that had become easy for them and left out details in their explanations. An engineer explained: "*you don't see those details necessarily and those are things that they [doctors] just naturally do without thinking… I think because they've done it so many times. They don't even think about it"* (C5E). The best chance to get a better understanding of clinical problems is to visit the operating rooms (OR): *"Engineers think they know what we [surgeons] do but they don't. They don't really know until they go to the operating rooms and actually see it in action… those engineers who go to the OR, when they come back they tell me: Well that was extremely eye opening to see"* (C3D). This could be a great opportunity to catch the hidden details and assumptions that may not be communicated verbally.

Similarly, engineers can always use drawings or prototypes to show the ideas they want to explain to doctors. This really helped to illustrate ideas better because otherwise engineers may be too deferential to doctors in their designs. Moreover, prototyping ideas assists in making group decisions as well as in marketing.

> *"I feel strongly getting us to the proof of concept stage or getting a project to a thing where there's an object sitting on a bench that we can look at is super important because then really those group decisions about what can happen next can really start to be made particularly people can look at it and then they can say things about the market… having prototype definitely help everyone to understand the idea better"* (C6E).

4.3.4 Blocking surgeons' time in advance

Lack of time, especially from clinicians, to put into these types of collaborations has always been challenging. Most of the engineers experienced that the doctors' schedules could interfere with the amount of their involvement to other projects, however securing some protected research time can resolve this issue: *"ensuring that the clinicians have that flexibility and have protected time that* *they're able to engage in is really important to actually be able to have a successful collaborative relationship with them"* (C4E).

While considering the fundamental factor of securing research time can eliminate the challenge of time, participants of this study also suggested other practical ways in their collaboration. To address time issues, especially the lack of doctors attending meetings, one of the doctors suggested to plan meetings well ahead of time so that they can block that time in their calendar: *"I have a full day of clinic and a full day of operating and I can't just cancel that to meet for an hour and I can't put my patients out without respect. So it does require some coordination and some advance planning and also requires honestly a little bit of independence"* (C3D). By acknowledging the busy schedules of doctors, respecting their time and deferring to what works best for them, the periods of collaboration with engineers can be more productive. Not only does this professional courtesy enhance overall organization, it also demonstrates understanding of one another's professional situation. As one engineer stated:

> *"the hours that they put into a surgical operations and seeing patients you know some of these clinicians see 50 patients a day and it's just a really grueling kind of thing. So I've tried to be cognizant about and try to make time for them when it works for them and understanding if they have to cancel, you know, two meetings just so we can get that third meeting. That's what I've tried to do and I think it's worked out pretty well"* (C1E).

It is also always helpful to hold a frank conversation at the beginning of each project and define clearly everyone's responsibilities as well as their required time commitment. Asking surgeons to schedule meetings during the initial phase of a project is an approach that this engineer recommended: "*if you cannot communicate the project is ultimately going to stall at one stage or another. I meet clinicians if they want to continue and have a project and make them put time into* *their calendar and if they're not willing to do that then that's a sign that they're not going to actually make the time to have a productive collaboration"* (C4E).

4.3.5 Embracing differences

Throughout the description of themes, the challenges as well as some techniques to address those challenges are addressed. The two unsurprising emergent challenges of this study, as literature has also repeatedly recognized, were: 1) finding doctors and scheduling meetings with them when they are busy 2) understanding the varied languages, vocabularies and terminologies that may be unfamiliar at the beginning of collaborations.

Members for these types of collaborative projects are professionals with different educational backgrounds and experiences. They acknowledge that diversity in background includes differences in languages, lifestyles, perspectives, approaches, and techniques in problem solving. While these differences may cause some challenges during the collaboration, they interestingly do not consider them as hurdles to their communication. Participants accept these differences as "par for the course" in these types of collaboration, with an ultimate reward of team members understanding each other better. In other words, they change from looking at challenges that may cause communication errors as barriers to their communication, toward learning and educating each other and making a more fruitful collaborative project. These differences provide a relationship-enhancing learning opportunity to help create new knowledge and understandings about each member's world and discipline which ultimately make the communication and collaboration successful. These differences along with gathered quotations are gathered in table 4.2.

Different perspectives are beneficial	*"The way that a clinician approaches a question tends to be very different than an engineer. They are much more focused on what the clinical implications might be or how to translate it to everyday practice? Whereas an engineer is going to just kind of have a general contact and the way that they approach a problem and solving it is going to be very systematic…So engineers will not have quite the same context of the clinical disease but they'll have a different perspective on how they systematically approach a problem…but those don't effect communication. Having both perspectives contribute to a much better product in the long term and better research question in long term"*(C4E).
Language differences are not a problem, and can be beneficial.	*"I don't I still don't understand the equations for forces or other mathematical part because we've written a number of manuscripts together so you know there's always a real technical part of it that I'm like I don't care about it and I don't want to know about it and I don't understand it. And so that part is always a challenge for me. But I generally understand the general meaning of their what they're writing or discussing. We really haven't had great communication difficulties and I don't think it's difficult it's just different*"(C2D)
Differences provide learning opportunities	*"….initially we figured that we did not have the same language—they did not know much about surgery and I did not know much about engineering and how we could link both and how we could share our knowledge and advance everyone's knowledge and technologies but over the years we have learned each other languages and have communicated more clearly and collaborated well…"* (C2E)
Collaborators overcome differences	*"Obviously if we're talking about details of anatomy the engineers aren't familiar with the anatomy. So you've got to dumb it down a little bit so they can understand. And on the other side, I have the foggiest idea about material properties of a particular metal alloy we're using. So they've got to dumb it down to explain to me… but these are not an insurmountable problem to communication*"(C5D)
Different languages cause fruitful collaboration	*"Different or even similar terminologies may cause misunderstandings but that's totally fine and totally acceptable… those types of mistakes are good mistakes and those are learning opportunities where you build a better fundamental understanding of the problem that you're approaching…. there is a realization that there will be mistakes or setbacks due to language barriers, but that ultimately the process of overcoming those barriers will build more stronger and more collaborative project"* (C4E)
Difference is not challenging	*"Different collaborators with different disciplines and languages are just par for the course. I don't think that I would consider it a challenge"* (C1D)

Table 4-2 Participants' views towards differences

4.3.6 Communication techniques: conclusion

Communication can be enhanced and its challenges can be mitigated through face to face meetings at regular intervals of sufficient frequency, continual exchange of mutual feedback, using drawings, prototyping the ideas, and going to the operating rooms, scheduling meetings with adequate notice, and embracing differences. All cases defined face to face meetings as a fundamental piece in their communication practices. It reduces confusion by facilitating multidimensional demonstration, prototyping, and a measure of focus absent from types of remote communication that risk distraction. The continual exchange of mutual feedback allows team members to know where a particular matter stands, so that they may effectively move forward to improve upon it. Having said that, engineers experienced difficulties getting feedbacks from doctors due to their busy schedules. In response, scheduling meetings in advance substantially increases the likelihood that everyone will be available to join the meetings as well as the level of engagement to complete the necessary tasks in collaboration. The inherent characteristic of such collaborative teams, e.g. differences in languages, perspectives, etc., may cause some challenges. However, the cases of this study take them as a means of enhancing their understanding and an ‘opportunity’ to learn from each other. Participants’ experiences indicate that one communication technique to address the challenges is steering the group's focus from the challenges to the facilitators instead.

Chapter 5: Discussion and conclusion

Effective communication between physicians and engineers when they work together collaboratively plays an important role to their success. Building on literature which suggests a need to study the communication and collaboration between physicians and engineers (e.g. Cummins et al, 2018), this study aimed to explore the interactions between these two professional groups. In this research, I explored the topics raised in communication practices of physicians and engineers who worked together collaboratively. Furthermore, I attempted to uncover the skills and techniques that these professionals incorporated to communicate more effectively with each other, which ultimately can foundationally support successful collaboration.

I found that certain factors were mentioned repeatedly in the literature about communication experiences between physicians and engineers (e.g. regular communication and meetings, maintaining respect and openness, developing trust) (e.g. Gale et al., 2011; Cummins et al., 2018). This study adds new factors that contribute to effective communication (e.g. the importance of building relationship, embracing differences, clarifying expectations and focusing on real clinical needs in projects, going to the operating rooms).

Previous studies (e.g. Reid et al., 2005; Ng, 2011) reinforced that since engineers and physicians are not exposed to each other's disciplines, their lack of exposure results in communication challenges. Participants of this study acknowledged that this knowledge gap and difficulty of understanding different terminologies and languages, especially at the beginning of their collaboration, was important to be recognized and addressed. Having said that, they did not find such challenges as *"an insurmountable problem to communication"*.

Moreover, to address the difficulties in understanding different terminologies and languages, the related literature recommends educational programs to bridge the knowledge gap between engineers and physicians (e.g Matsuki et al., 2009). However, this strategy might not work for physicians and engineers who are already practicing in their fields. This study suggests that effective collaboration requires an environment in which both physicians and engineers are exposed to each other's professional cultures and disciplines. This means a strong collaborative setting not only helps these two groups to get familiar with each other's tacit knowledge and languages, but more importantly it creates a platform that helps them understand the needs, strengths and weaknesses of each discipline. Previous studies have noted the importance of increasing interdisciplinary interaction during development of medical devices to improve patient care and safety. (e.g. Ng, 2011; Yoda, 2016). This was also evident of the dyads in this study who had worked collaboratively together for years. In essence, the participants found that increasing interaction and interdisciplinary cultures helped them a) achieve positive and effective outcome/results and b) provide learning opportunities during the course of their interaction and togetherness. As described by one of the physicians, it facilitates "*answering important questions that are necessary to help make decisions for the operating room or decisions for patients*".

To facilitate such interdisciplinary interaction, this study suggests more attention to the integration of real clinical needs as well as the engineering potentials for implementation. When developing new innovative devices for health care users, engineers increasingly rely upon the expertise of physicians to better understand the clinical needs. With that in mind, this may need to be the main focus and motivation behind medical device design and development. It is essential both parties make a concerted effort to better explain the detail of real clinical needs (physicians) and the design trade-offs and limitations (engineers) in order to facilitate interdisciplinary interaction.

Implementation of successful device design requires a balance of those respective understandings and interests. What works best for physicians may not be practical from an engineering perspective and what works best from the engineering perspective may not resolve the clinical needs of the physicians.

To enhance such understanding, this study suggests continuous bidirectional communication. Holding regular meetings helps both groups better understand each other and thus communicate more effectively. Participants in this study suggested that simply blocking off physicians' time can facilitate communication. They acknowledged that physicians are busy professionals and it is hard to engage them. However, scheduling meetings in advance encourages physicians to commit and attend meetings. Holding regular meetings and open, honest, continuous interaction can lead to stronger communication with a greater focus on the end users. That focus occurs as a natural outgrowth of overcoming the aforementioned barriers in communication.

Moreover, listening attentively has been identified as a way of improving communication practices. For example, Propp and her colleagues (2010) looked at the nurse-team communication and its effect on patient outcome. They found that active listening is one of the factors that promotes positive synergy and effective communication. When describing active listening, the authors described nurses as "welcoming questions from team members and addressing team members' concerns in a nonjudgmental manner" (p.23). Negative listening was explained as failing to nonverbally show respect to other team members when they were speaking. One of the participating physicians in my study highlighted the importance of active listening as well:

> *"[active listening is] when the engineers are explaining what they're doing and I am engaged or whoever clinicians [or engineers] are engaged, and are not on their phone at the same time or are not in the operating room at the same time, [instead] they have focused*

> *attention and are processing the information that's being provided to give thoughtful responses back*” (C3D).

Therefore, engaging fully in conversation with the intention of understanding the other, rather than judging or thinking of constructing a better argument, is key in practicing attentive listening.

Aligned with holding regular meetings and listening attentively, the findings of this study also demonstrate that clarifying expectations through defining intentions at the beginning of a project can build stronger relationships. A clear articulation of intentions appeared to provide a pathway that team members could follow. Moreover, other elements such as recognizing hidden assumptions and capturing technical details can enhance clearing up expectations and understanding each other. Engaging in discussions and providing constructive feedback can uncover some of these hidden assumptions. To support a stronger clarity of vision, this study suggested some specific techniques such as incorporating different visual techniques such as drawings or brainstorming on whiteboards, prototyping an idea, and going to the operating room. These communication techniques can also help identify important details that might have already been missed during verbal communication.

Furthermore, much of the current literature on effective communication has identified ‘differences’ among physicians and engineers as a challenge. Surprisingly, the participating physicians and engineers in this study described how existing differences among each other was more of a facilitator for their communication. Differences in ideas and ways of thinking are an inevitable part of communication. Rather than seeing differences as a challenge, a burdensome force of opposition, or something to be discouraged, these physicians and engineers tried to see the opportunity of learning in the situation. Opportunities to learn, improve, or adjust in a way that leave them with a better understanding of each other and working more effectively together.

For example, engineers appeared to be more focused on the technological aspects and mechanical processes behind the development of devices, while physicians looked more toward issues of user friendliness and general application efficacy for achieving desired medical outcomes. These separate focus areas reflected the differences in their professional fields and expertise. While it is initially challenging to bridge these differences, the spirit of being and working together as well as their exposure to each other's disciplines ultimately produced better results. Indeed, the differences did not discourage participants to stop their collaboration. Instead, differences were taken as learning opportunities towards making their communication better.

Overall, the insights from this study suggest that a good collaborative setting consists of an environment where team members are interested in working together, share workload equally, are aware of their own strengths and weaknesses, and are honest, respectful, and open to different perspectives. In such an environment, different perspectives are viewed in a positive light—as valuable views to be considered rather than to be avoided. In other words, instead of overpowering their differences, team members are focused on achieving their common goals.

With a more careful analysis of the finding, a pattern emerged as to the factors contributing to successful communication. It seemed that some communication elements focused more on 'personal' or individual characteristics, while others were more 'contextual' or structural aspects within interactions. The current literature in this field looks at these factors as discrete characters of effective communication and does not outline the interaction of these elements (e.g. Huggett et al., 2011; Yoda 2016; Cummins et al., 2018). The following diagram attempts to show the intersectionality of these 'personal' and 'contextual' factors.

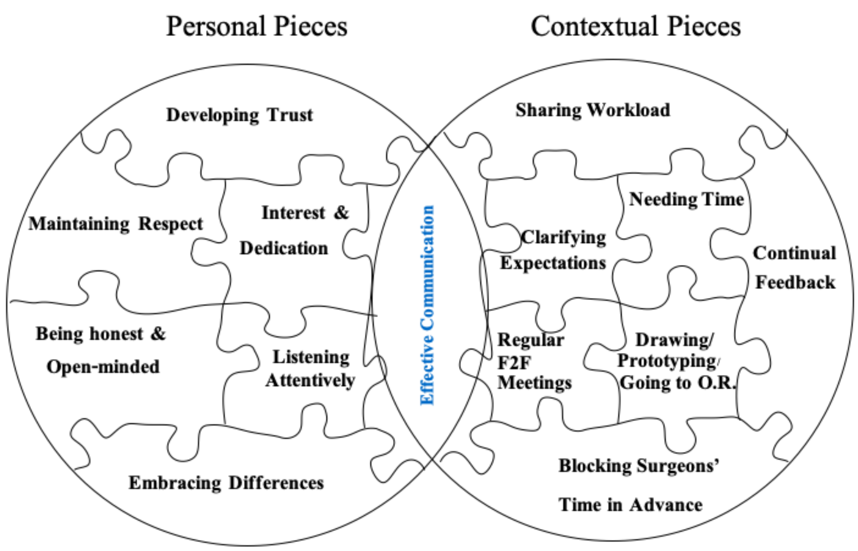

Figure 5-1 A model of contributing factors to effective communication

This model illustrates that effective communication occurs when personal and contextual sides intersect. In other words, personal and contextual factors are not two separated pieces. In fact, they work together and give meaning to each other. In the personal realm, team members are interested, honest, respectful, open-minded, good listeners, trusting and embrace the differences, while they observe the structural characters that influence their interactions. Contextual factors, meanwhile, emphasize the importance of creating an environment where team members attentively listen to and openly communicate with each other. Such an environment demands that the members reflect on their assumptions about each other and their respective fields, are clear about their needs, expectations, roles and responsibilities, and are honest and respectful in their interactions. By unpacking and making visible this model, it may lead to the taking the foundational steps needed to support the development of effective cross-disciplinary teams. Therefore, the more aware and committed the team members are of both the individual and contextual characters, the more engaging and effective their communication will be.

5.1 Transferability

Recommendations outlined in this study may be applied to other inter- or multi-disciplinary collaborative projects and contexts, irrespective of profession, discipline, or even task. Factors such as attentive listening, embracing differences, holding regular meetings, mutual respect of differentiated roles, sensitivity to schedules, and others mentioned above can help build any relationship and facilitate communication between professionals—whether it is educator and lawyer, kinesiologist and pharmacist, accountant and forester or others.

5.2 Limitation and future studies

This study and the existing literature provide recommendations on improving team communication without providing a simplistic approach or 'rigid recipe' to improve communication. Future studies may be better suited to preparing manuals or guidelines for such collaborative teams to better support effective communication and collaboration.

The data also consisted of relatively stable pairs that were long-standing and relatively functional. Therefore, dyads appeared to work well through challenges. The insights are limited because there were not obvious traces of dysfunction in the relationships or because the relationships were not newly formed. Future research is needed to understand how long partnerships have been collaborating; any hierarchy structures and/or conflict might impact communication on these dyads.

There are many possibilities for future research in this area that could be focused on changing the types of teams studied, the data collected, the size of the unit of analysis and/or testing the framework that emerged from this study. For example, future studies might focus on 'unsuccessful collaborations' or new teams as a way of diversifying the applicability of the approach. Other studies may choose focus groups in which both engineers and physicians participate and interact in creating a shared set of perspectives and feedback. As well, observational studies could further add depth and rigor to balance self-reported perspectives with 'watching teams in action'. This can create an opportunity to further investigate the emerged factors from this study and explore new factors (e.g. understanding power or hierarchy) that may arise.

The approach taken in this study could also be applied to other disciplinary dyads (e.g. geneticists and pharmacists, kinesiologists and physiotherapists, etc.). Comparing team dynamics and effective communication across other disciplinary dyads might further strengthen the conceptual framework and provide new insights to engineer/physician teams. As well, this study focused on dyads; future research could extend this research approach at a team-based level (i.e., groups of engineers and groups of physicians working together). This team-level approach—whether they are physicians and engineers or other disciplines—could look at the group interaction effect of personal and contextual factors in their collaboration.

5.3 Conclusion

This study contributes to the existing literature by focusing on the communication experiences of physicians and engineers who have been working together. Collaborators, physicians and engineers, should be aware that interdisciplinary collaborations are possible and can be fruitful. However, this only holds true as long as matters of communication including both personal and contextual factors are taken into consideration and consciously structured into working relations. Maintaining effective interdisciplinary communication might be challenging, however, it can be facilitated by gathering interested and dedicated collaborators who work together equally and share the same goal. In other words, despite difficulties that may arise in collaborative work, the case studies illustrate that the benefits of collaboration between physicians and engineers are substantial, and the integration of ‘contextual’ and ‘personal’ pieces of communication are paramount to achieving effective communication.

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Appendices

Appendix A Vignette

"Traction table project: Engineers and a surgery resident work together"

It is Tuesday morning and I am on my way going to the Centre for Hip Health and Mobility (CHHM). On the fourth floor, I will complete my first half of my observation in one of the biomedical engineering labs. I am thinking about this building which has many biomedical engineering labs and is located next to the Vancouver General Hospital (VGH); asking myself: Is this building right next to the hospital so that engineers can have access to and communicate with the clinicians easier? Are there any collaborative projects between engineers and clinicians? How might collaborative projects look different from other projects in which only engineers work?

I found myself in a small room, with many different tools hanging on the wall! Three engineers are working on their project—a traction table! Music plays in the background, and after 10 minutes, the engineers start working on their tasks. Two of them are on the main device trying to make some holes from which to later insert screws and attach them….the other engineer is measuring something beyond my visual purview. An engineer uses the electric cutter to saw part of the wood; later the engineers attach this part to the main device where they were trying to make holes for the aforementioned screws. The engineers are not happy with the shape of the screws! One went to find the right screws from another lab. Now there is a break time and I ask, "Do the other teams have residents or clinicians?" "We are the only team that is lucky enough to have a resident who studies in our engineering program," answers one of the engineers. He continues, "The other teams meet clinicians every three weeks so they can ask their questions. But they cannot show their device that they are working on because usually clinicians and surgeons are busy people and the students need to go to the hospital." I smile with understanding and reply, "You are fortunate then to have this resident on your team!" The engineers emphatically nod yes, a second one interjecting, "He is available whenever we have questions, or even if we want to test the device!" This traction table exists on the market but is very expensive, so they are trying to design it in a way that costs less. This resident has worked with this device and he has very good experience and knowledge, something that the engineers cannot gain from a book or watching videos! Now there is a laugh about how theories look different in practice.

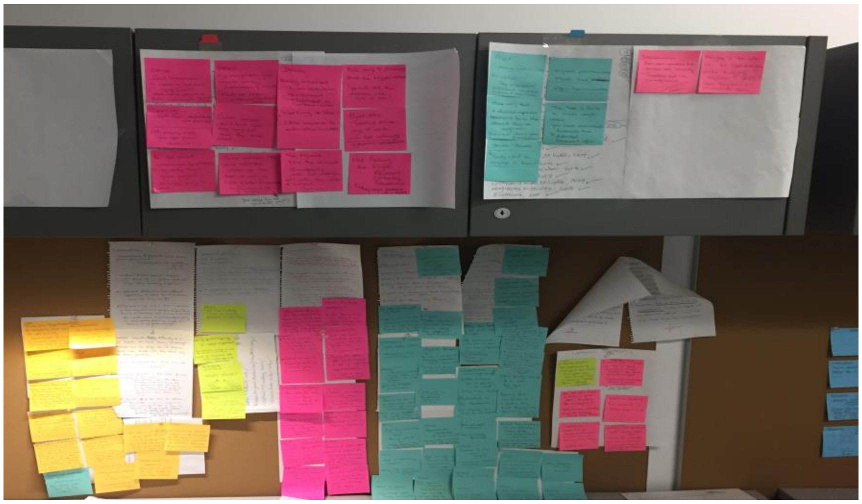
I completed the second half of my observation in which the resident joined the engineers. They took the device to another lab where there was a C-Arm Xray, so that they could test and see the image. They wanted to test their device (traction table) to see if it works properly. This lab looks more like an operating room! The engineers were very excited to have the device ready to test and show, but the resident was more focused on the result, testing it to make sure it works safely for the patient. There wasn't any music playing in the background this time. One of the engineers tried to demonstrate what they have worked on so far to the resident. He laid down and put his legs on the traction table. The engineers were so happy that his legs fit in the traction table; they were satisfied with their design. The resident was happy too. Though he had a question concerning the patient: "This device will be used by patients who are injured and cannot move their legs freely. They probably won't be able to do exactly what you are doing now! We need to consider their legs movement limitation in the design." The engineers then started to think and went back to measuring and revisiting their ideas. At this point, the resident left the lab knowing that the engineers would be applying his idea.

Observational relationship to my project: The engineers were more focused on the design of the product and the fact that they had made such a device that worked. For the residents/clinicians, they were more concerned with patient safety in making sure that the device works properly. This difference in their goals and ways of thinking does not reflect a negative aspect/barrier but shows the beauty of collaboration, bringing technology and safety together!

Appendix B Interview questions

1. Introduction: What is your full name and professional background? What attracted you to this line of work?
2. How do you define/describe the collaboration work experiences with clinicians? what was it like? Would you prefer working alone or together with clinicians/engineers in the future?
3. How do you define effective communication in a teamwork?
4. What are the challenges/benefits of communication that you have experienced? What were the strategies that you used to achieve those benefits?
5. What did you think of communication with engineers/clinicians before working with them? Was that change after collaboration?

Appendix C Color coding



Appendix D An example from codebook

Miscommunication	No regular meetings	• Holding regular meetings helps communication. • Using visual techniques helps communication. • Continual feedback helps communication.
	Not using visual techniques	
	No continuous feedback	
	Not knowing what others need to know	
	'They Thought it Was Not Important'	
Challenges	Difficulty in getting funding for engineers	• Importance of addressing clinical needs • Organizing meetings way in advance • Clarifying expectations up front • Being immersed into an engineering/clinical environments • Increasing interaction
	Not asking clinically relevant questions (affects engagement)	
	Authorship order	
	Not allocating enough time (Dr.s are busy)	
	No continual feedback	
	Gap between research question & real clinical needs	
	Language and vocabularies (only at the beginning of the collaboration)	
	Absence of communication	
	Not having dedicated members	
Active listening	Fully present in discussion and meetings	• Helps in maintaining effective communication
	Helps in giving thoughtful responses	
Relationships fell apart when…	It is not bidirectional	

	Members are not involved in the whole process	• Importance of sharing workload • Being equal partner
	Expecting only one person can do all the work	
	Not willing to put enough time	
Engagement increases when…	Thoughts are valued equally	• Respecting each other's discipline • Being equal partners • More fruitful collaboration • Developing trust • Strong working relationship
	All members listen	
	Sharing thoughts with no judgement	
	Members feel they can openly and freely share their thoughts	
Using visual techniques	Going to the operating rooms	• Catching details missed in verbal communication
	Prototyping	
	Drawings	
	Whiteboard brainstorming in meetings	